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## Mechanico-Chemical Processing

TO THE LONG SERIES of special theme issues dealing with the unit operations of chemical engineering, the editors of *Chem. & Met.* are about to add what they hope will prove a significant and helpful contribution. When they first undertook the planning of this issue on "Mechanical Processing of Chemical Materials" they realized that not all mechanical operations could come within its scope. Instead, they selected three of the most important groups of related operations—viz., disintegration or size-reduction, mixing, and mechanical separations. Some of these unit operations are fairly well known to the chemical engineer, while others, which have been developing rapidly, lie somewhat outside of his specialized field. A thorough-going survey and summary seemed more than justified. But how proceed?

First came a set of tentative specifications. Then through study of the current literature and by personal interviews and correspondence, the editors surveyed the field of each prospective article to see how it might appropriately be fitted into these specifications. What did the chemical engineer want to find in such a survey as was planned for him? First and foremost, it was believed that he wanted to know about new methods for accomplishing given results. He wanted to learn the principles of those new methods in order to be able to apply them to the solution of his own problems. In the case of the older methods, he wanted to know about improvements in equipment and operating technique leading to new efficiencies. He wanted information on performance—yes, and costs

where available—which would assist him in making a preliminary selection of methods. Not unmindful of the fact that a little knowledge may prove a dangerous thing, it was early realized that in many cases the chemical engineer would be most foolish not to rely on the advice of the equipment specialist in making his final selection. Nevertheless, a comprehensive and authoritative summary can help materially in narrowing the field of that selection.

This, then, was the general aim. Unfortunately, not all of the chosen subjects could be made to fit it closely. Crushing, grinding, pulverizing and other operations of disintegration, as well as mixing and blending, are largely empirical. So are many of the mechanical separations. Here, particularly, the printed word is no adequate substitute for experience. Hence in many of the articles, performance and application data were sought in lieu of fundamental laws. In others, as in the study of filter media, the attack was on a little-understood phase of an otherwise much-written-about subject. Again, there were stores of accumulated experience that could be tapped, as in the two leading disintegration papers. In the case of several of the separations, most of the development and application have been in the mineral industries, and here a thorough discussion of fundamentals seemed to be warranted.

With this explanation of plan and purpose, the editors of *Chem. & Met.* present a new and critical cross section of a group of unit operations which the chemical engineer has largely inherited from the earlier arts of mechanical, mining and metallurgical engineers.

THIS ARTICLE introduces a group occupying the next 18 pages, dealing with several phases of size-reduction

# A View of Grinding Fundamentals

BY WALTER L. MAXSON, engineer of the Mining Department of Allis-Chalmers Mfg. Co., Milwaukee. A contributor of several important papers on grinding to the A.I.M.E., Mr. Maxson has been actively associated with both the teaching and practice of metallurgical engineering since 1915.

TO THE CASUAL OBSERVER, disintegration operations are likely to seem relatively simple. However, those who have occasion to work intensively in this field are soon forced to modify this view when they come to realize the complexity of the various factors which affect the end result. Before looking into these factors it will be well to define the field and particularly to delineate the various types of unlocking required in practice.

Grinding refers to relatively fine size-reduction, but may be described as coarse, intermediate, or fine, with the limits roughly set 6 to 35 mesh for coarse, 35 mesh to 70 per cent minus 200 mesh for intermediate, and 70 per cent minus 200 mesh down to 10 microns for fine grinding. Such designations, however, are not fully descriptive inasmuch as they portray the unlocking only in terms of mesh size. A more exact method of indicating the disintegration required is to define it as to: (a) mesh size; (b) release; (c) specific surface; and (d) grouping. These terms are not arbitrary but may serve to draw attention more forcibly to the exact nature of any grinding problem with which the operator may be faced.

"Mesh size" grinding is practiced in many industries where it is necessary only to control the ultimate product in terms of some limiting mesh.

"Grinding for release," or "unlocking grinding," has reference primarily to the type of operation required for many chemical and metallurgical processes where it is necessary only to expose surfaces for attack by gases or solvents as, for

example, in exposing particles of a valuable material that have been locked in a gangue.

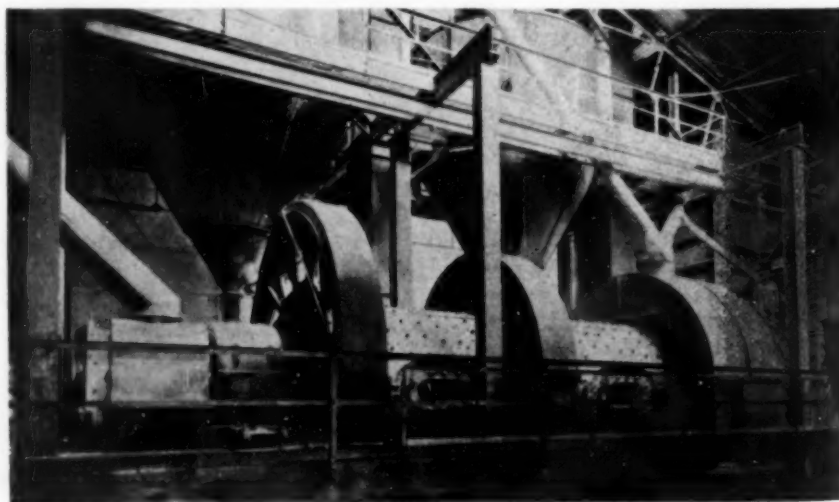
"Specific surface" grinding has reference to grinding for the production of surface in contra-distinction to grinding through a limiting mesh. Although it has been practiced in various industries for many years, the methods of control are new. An empirical measurement for the surface in the product is now used. In general, the specific surface is designated as the square centimeters per gram of ground material, and one of the newer methods of measurement is to use a turbidimeter, which offers a reasonably accurate and rapid method of making empirical comparisons.

In some industries a normal product would have a specific surface from 1,650 to 1,700, whereas an

extremely fine product would have a specific surface ranging from 2,600 to 2,800. The latter in terms of mesh size would represent a product which might possibly run 94 per cent passing 325 mesh, or approximately 96 per cent passing 40 microns, but it is possible to grind to these limiting mesh sizes without developing the required specific surface. Therefore, it is proper in operations of this kind to control the grinding units by surface measurement rather than by mesh measurement.

"Grouping or size modulus" grinding has reference to those operations where it is desirable to control the product within certain ranges of mesh size. While this is not at all an unusual requirement it has been brought to the fore markedly in recent years by the work of engineers in the aggre-

Three-compartment dry cement mill closed-circuited with air separators



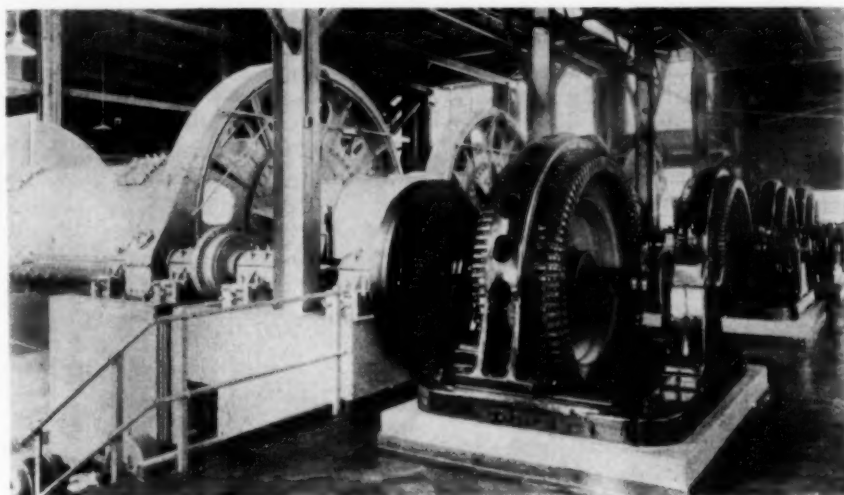
gate industries where it is desired to produce mixtures having minimum void space. The practice has resulted in some rather remarkable savings in raw materials required.

A careful study of disintegration operations reveals that they take place as a result of (a) impact; (b) differential movement of adjacent surfaces; or (c) combinations of both. Further analysis of differential movement shows that here again the action may be produced by surfaces whose movement is more or less controlled, or by surfaces whose movement is heterogeneous. There are, obviously, combinations of both. For example, the average cylindrical mill may, and usually does, involve both impact and differential movement, and while the action may be controlled within reasonable limits, it is an example of an operation which may be properly designated as heterogeneous. Those types of grinding wherein impact is of relatively little importance, and where the surfaces are controlled, are represented by mills having fixed or rotary die rings with rollers or balls acting as breakers. There are also the simple impact devices such as the swing hammer pulverizer, in which the breaking is effected very largely by impact.

Each of the several methods of disintegration is, in turn, affected by a number of factors which are briefly discussed below. Two of these, constitution of the feed, and the type of disintegration desired, are uncontrolled factors, while the remaining nine are more or less inter-dependent variables. A change in one may require compensating changes in one or more of the others and it is this fact which demands from the operator most careful attention if best results are to be secured. These factors include: velocity of impact, character of the surfaces, size of the feed, mill speed, type of liner, weight of the charge, size of the grinding media, rate of flow, and the type of circuit.

**Constitution of the Feed**—The physical constitution is of utmost importance and, to a large extent, may impose limitations on the machines and methods used, and the results secured.

For the sake of simplicity any given material may be considered as consisting of grains bound together by a matrix. In the case of purely crystalline products there may be practically no matrix material pres-



Cement plant 40-ft. multiple-compartment mills with 800 hp. motors

ent. Experience has shown that, when breaking crystalline products with or without matrix present, there are distinct grain sizes which may be released at various stages in the operation, which may or may not offer great resistance to breaking. In some cases it has been found relatively easy to break the matrix and quite difficult to break the grains. In other cases the matrix is resistant and the grains relatively easy to grind once the matrix has been disintegrated.

It must be realized that this is only a rough approximation of the actual conditions, as rupture of grains and of matrix occurs simultaneously, but it is significant that examination of products at various stages in grinding will often reveal a major accumulation of resistant grains which are difficult to grind. These may be found at various stages even with the same raw material. In some cases it has been found that a slight alteration in the grinding limit will greatly increase the capacity, when it becomes possible to avoid breaking the extremely resistant grains.

Reverting to the question of structure, the initial strain or stress inherent in the material is also to be considered. This may be modified by previous treatment. For example, in disintegrating certain alloys it is found that if they are chilled when cast, disintegration is greatly facilitated as compared to slow cooling. In grinding cement clinker and similar products, it is sometimes found that quick air cooling materially modifies the grinding resistance. The use of alloying materials has been resorted to in

some cases where easier disintegration is sought. Roasting in most cases also results in a marked decrease in grinding resistance.

The abrasiveness or coefficient of friction of the feed is also an important element in proper selection and operation of grinding units inasmuch as certain types of equipment cannot be used for extremely abrasive materials. Those materials which are slippery, such as coke or some of the coals, offer resistance because of the difficulty in nipping the slippery particles between the grinding surfaces.

**Type of Disintegration**—This has been covered in previous paragraphs, but it is proper to point out that it is a major controlling factor in the selection of equipment to be used.

**Velocity of Impact**—The velocity with which the grinding media strike the material is, in general, related to the constitution of the material, and to a certain extent to the size of the feed used. Investigations have been made on this point, and it may be said that with materials which are extremely hard to break, particularly in the coarser mesh range, higher velocities are warranted. However, with softer materials the use of high velocities of impact may result in low power efficiency. There is also a relationship between the velocity of impact and the choice of materials used in the disintegration unit, for with higher velocities wear may dictate the use of special alloys. This, in turn, may lead to an uneconomical combination as regards ultimate cost of grinding.

**Character of Surfaces**—This heading covers not only physical charac-

ter and composition of the grinding surfaces, but also their shape, and progressive changes in shape due to wear. In the case of cylindrical mills with heterogeneous action of the grinding media, and with differential movement as the predominating grinding action, it is necessary that the particles be nipped between the grinding media. A recognition of this fact has lead to various experiments making use of several different shapes such as cubes, tetrahedrons, cylinders, spheres, concave-convex bodies, spheres connected by cylinders, and other miscellaneous shapes. Comparisons involving both mesh-tons and surface produced within the range of normal grinding show little advantage in special shapes, although in the case of extremely fine grinding some marked increases have been shown.

In any case, it is necessary that the grinding media offer the necessary surface without at the same time impeding the flow of the material to be broken. It is often desirable to discharge the entire content of a grinding unit regularly and eliminate the slivers, flats, and distorted shapes resulting from wear. Upon replacing the charge a marked increase in capacity is apparent.

It is also necessary that the grinding media shall be of such shape that they are not sluggish in their movement, as the production of new surface is affected only by relative movement of the grinding media, and a sluggish charge is rarely an efficient charge.

Where controlled surface units are used for disintegration, the progressive change in shape may become quite pronounced if the material is at all abrasive, and may dictate the selection of materials used, and the application of such units for disintegration problems.

The relative weight of the media used for disintegration is also of importance, particularly in those cases where materials of high specific gravity are to be broken. This factor is not always recognized, but must be seriously considered. Unfortunately it is not economical to use the special weighted grinding media, but the use of heavier than normal grinding bodies has been adopted in a limited number of cases.

**Size of Feed**—The size of the material fed to the disintegrating unit is usually determined by economic factors. For example, it is usually cheaper to break the ma-

terial down to  $\frac{1}{2}$  in. or 4 mesh in gyratories or rolls than to feed material larger than this size to cylindrical mills or similar types of grinders. The size of the feed is related to its constitution, and in the case of soft materials there may be very little gain in the grinding stage by charging fine feed, whereas in other cases the preliminary breaking unit may provide a considerable amount of finished product, thus relieving the grinding stage of a part of its duty. In general, it may be said that grinding is more expensive than crushing and there is, therefore, incentive to reduce the size of feed within economical limits.

The size of the feed is quite important as regards the selection of the grinding media. The latter must have sufficient mass and develop sufficient kinetic energy to break the coarsest material effectively. However, as the mass of the individual units is increased the area available for grinding and the number of points of contact available per cubic foot of volume are decreased and it is, necessary therefore, that an em-

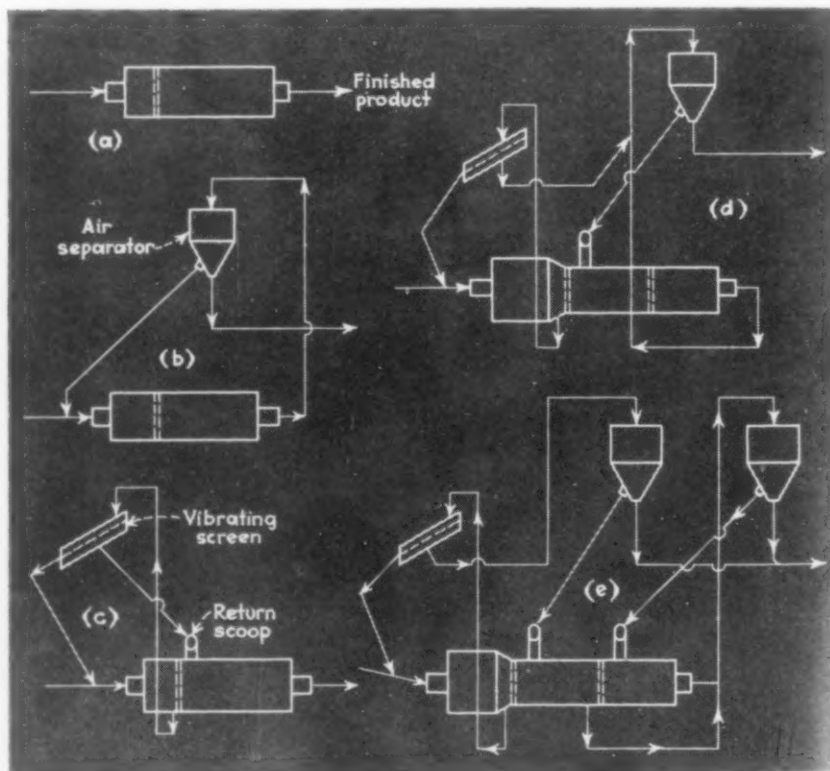
pirical balance be established between the size of feed and the size of grinding media.

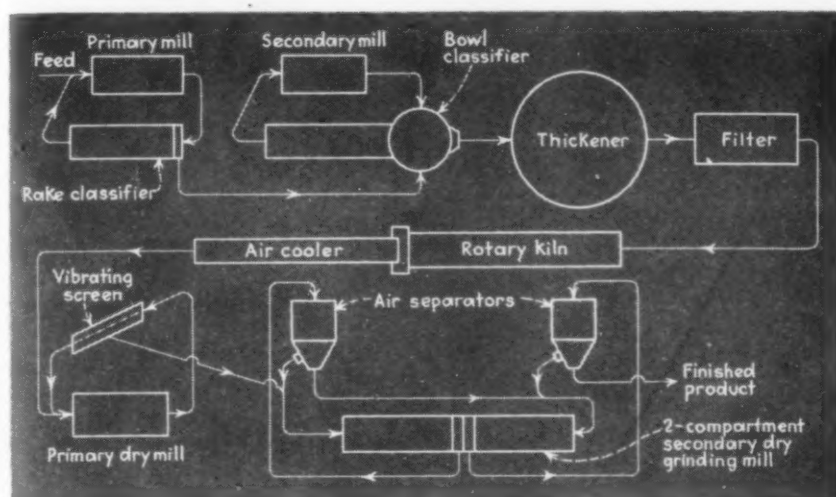
It has been repeatedly demonstrated that as the size of the material is reduced, progressively smaller grinding media can be used economically. This is particularly emphasized in those cases where finished material is progressively removed from the circuit. The practice has probably met its widest application in the grinding of cement clinker. The cyanidation industry has also recognized the necessity for proper selection of grinding media with the result that some marked increases in capacity have been secured by changing the ball size.

**Mill Speed**—In cylindrical grinding mills, speed is important in that to a large extent it determines the number of cycles made by the grinding media in a unit of time. It also serves to change the contour of the grinding mass. In those cases where it is desired to have impact predominate it is necessary that a higher speed be used.

There has been a certain amount

Typical dry grinding circuits including: (a) simple two-compartment mill in open circuit; (b) two-compartment mill closed-circuited with air separator; (c) two-stage set-up with primary compartment closed-circuited; (d) efficient two- or three-compartment circuit closed with a screen and air separator; (e) highly efficient three-stage system closed-circuited in each stage





Latest type of closed-circuit wet and dry grinding flow sheet recently installed in a large portland cement plant; note double stages in both wet and dry ends

of loose thinking in connection with mill speeds, particularly with reference to the term "critical speed." The critical speed is an evaluation of gravity versus centrifugal force but, unfortunately, the real critical speed developed in a cylindrical grinding unit, while related to the theoretical, is affected by other factors such as the sluggishness of the charge, weight of charge, shape of liners, and relative size of feed and grinding media. In wet grinding the amount of moisture will also affect the charge contour. Essentially, the shape of the charge contour with specific reference to the location of the apex is of major importance in determining the type of grinding and the work to be done in a given unit. The same apices may be secured in the same mill by operating with a low ball charge at a high speed, or by operating with a higher charge at a lower speed. However, experimental work in the cement industry has led to the conclusion that ball charges should not be too low except for special cases and types of operation. Furthermore, it is evident that the mill speed must be correlated with the weight of charge to secure optimum grinding.

There have been numerous attempts to alter the action of the grinding media by modifications in the shape of the grinding unit. Careful tests show that the amount of new surface produced per revolution of the mill is practically constant for any given unit. Little or no advantage in net production can be gained by attempting to alter the normal

movement of grinding media by changing the shape of the unit.

**Type of Liner**—Liners are used in cylindrical mills for two purposes: to protect the unit against wear, and to provide means for controlling the action of the ball charge. The proper contour of liner is of importance, and should be carefully considered from the standpoint of mill speed and weight of charge used. For example, if the liner provides a maximum lifting effect it is necessary that the speed be reduced, for otherwise the grinding media may be carried so high as to reduce their effectiveness in grinding. On the other hand, with smooth liners which offer a minimum of lifting effect, the mill speed must *per se* be increased for the same ball action. With all types of friction liners there is a steady change in contour and decreased lifting effect during the liner life. The mill speed should be selected for half-life contour, although variable speed operation would be preferable.

There are many different types of liner and each has its own advocates. It is sufficient to state that no one type is best suited to all problems. However, the proper selection of liner may not only materially influence the capacity of a given unit, but also the ultimate cost of operation, as reflected in both capacity and wear.

**Weight of Charge**—The weight or volume of the charge has already been mentioned but, at the risk of reiteration, it should be emphasized that it is related closely to the speed

at which the unit is to be operated. If the charge level is too high there will be interference with the free movement of the grinding media which will serve to reduce capacity.

**Size of Grinding Media**—The size of the media used for grinding, whether rods, pebbles, balls, or other shapes, is a major consideration. If impact is desired the kinetic energy of the individual unit becomes quite important, sometimes even more so in wet grinding than in dry grinding since there may be a pulp pool in the unit which tends to rob the falling media of a portion of their kinetic energy before they do useful work. In any case, it is desirable that the grinding media be large enough compared to the maximum size of feed so that they may effectively nip the particles.

It is to be recognized that there is progressive wear on any grinding medium and it is, therefore, desirable that this be taken into account in selecting the initial charge and in replacements. In dry grinding, where the rate of wear is usually considerably lower than in wet grinding, the progressive change is less marked, as it is in the heterogeneous type of mill, as compared with the controlled surface type. It is sometimes necessary to remove the ineffective grinding media periodically if reasonable efficiency is to be secured. This is particularly true of media which change form materially as they become worn.

**Flow Rate**—The determination of proper flow rate in any type of grinding device is subject to experimental confirmation by actual operation. It is improper to assume that any specific flow rate will give best results until it has been proven in practice.

The term "flow rate" refers primarily to the average rate of travel of material through the unit from feed to discharge. It is recognized that increases in flow rate where the units are operated in closed circuit make it possible to modify somewhat the distribution of surface and mesh size produced by a given unit.

The production of fine sizes requires a great expenditure of energy and a grinding unit obviously should be operated to reduce to a minimum the production of sizes finer than required. There are limitations to the flow rate, but these have been demonstrated to be different for each problem. Laboratory tests

(Please turn to page 282)

# Size-Reduction by Impact

By JOHN T. FOWLER, who is a mechanical and mining engineer of long experience in the pulverizer and crusher division of the Jeffrey Manufacturing Company, of Columbus, Ohio. His work has included design, test and application of such equipment.

IN SIZE-REDUCTION of materials lie unlimited opportunities for improving the production processes of many industries. Especially is this true in the diversified field in which chemical engineering methods and equipment are applied. Here literally hundreds of solid raw materials and derived products must be reduced in size before or during chemical processing in order to bring about more intimate contact or more effective reaction with other substances. By far the greatest number and largest tonnage of such materials are brought down to the intermediate size range, i.e.,  $\frac{1}{4}$  in. to 40 mesh, and size-reduction by impact is perhaps the most widely practiced method.

First, however, let us consider some of these chemical process raw materials that are reduced in largest tonnages. Coal leads the list, of course, and whether for fuel or process use, its specifications continue toward ever smaller sizes. Stone for lime and cement is crushed, ground and pulverized and then re-pulverized in the finished product. Wood is more efficiently used for paper pulp, for the extraction of resins and tanning materials, or as wood flour for dynamite and plastics—only after proper size-reduction.

Another excellent example of what a new application of size-reduction can mean to a chemical process industry is furnished by a development in the cane-sugar mills of Hawaii which started back in 1914. The basic idea was merely to shred the cane before its passage through the roll crushers which theretofore were the only reduction facilities used. The result was an increase in extraction of the sucrose amounting generally to 1 to 2 per cent—in some

mills, even more. One mill claims that an increased extraction of one per cent gave them an additional grinding-season revenue of \$40,000 to \$50,000; another mill figured a saving in fuel oil of \$6,000 per year.

A recent application of knowledge and experience gained during a sea-going size-reduction operation of World War days is of more than passing interest. Long-time readers of *Chem. & Met.* will recall that the sea-weed, kelp, was harvested on the Pacific Coast in order to help meet the shortage in supply of potash and acetone. Investigation developed a floating size-reduction plant on a self-propelled harvester barge. The cut kelp was carried up a 24-ft. sloping conveyor to a swing hammer mill which reduced it for handling by pumps to storage. The plant on shore made the extraction of potash and iodine and fermented the residue to yield acetone (see *Chem. & Met.* vol. 18, pp. 576 ff. 1918). Rather recently the Government applied this self-same idea to the eradication of water-hyacinths, a floating plant which greatly obstructed navigation in the streams, bayous, and canals

of the South. Once pulped by hammer mills, the hyacinths are killed and readily sink to the bottom.

Many other equally interesting examples might be cited to show how the idea of economy through size-reduction is constantly spreading from one industry to another. In the great majority of these applications within the intermediate size range, the records show that the swing hammer mill leads all other types of size-reduction machines, not only in the number of materials handled but also in number of sizes produced.

The swing hammer mill is essentially used for crushing and pulverizing semi-abrasive, pliable materials such as stone, minerals and dry chemicals; also for shredding or otherwise reducing practically every kind of fibrous and pulpy material. It is operating in process industries of all kinds—chemical plants, cement, pulp and paper mills and other forest product plants such as those for turpentine and resin extraction, the manufacture of tanning extracts and insulating lumber.

While, as stated, the swing hammer mill successfully reduces many

## SIZE-REDUCTION, a New Term

Throughout this article the author painstakingly refers to the physical reduction of materials by machines as *size-reduction* (two words, hyphenated). This he does advisedly, with the suggestion that this terminology might well be adopted as standard usage in the broad coverage of crushing, pulverizing, grinding, milling, disintegrating and shredding, all of which are variously understood as between fields of use, especially if applied broadly. Heretofore the single word *reduction* has been widely used for the purpose. But, patently, its use is unfortunate, particularly in the process industries, where the word already has the chemical meaning of de-oxidation and frequent mechanical application in connection with the *speed-reduction* mechanisms of power-transmission machinery. *Size-reduction* is unqualifyingly self understood and sufficiently broad for the proposed over-all meaning.

materials and makes a wide range of sizes, it has its limitations and does not supplant the other types of machines, which have merit in their particular fields of work. It is virtually impossible to generalize or set down specific limitations because they depend entirely on the character of material handled. In lieu of this, the only safe guide is to rely on the experience of the equipment manufacturer, backed by actual test in the case of hitherto unworked or doubtful materials.

The great flexibility of application and operation of the swing hammer mill lies in its design and operating principle. The feed enters the machine from above and falls into the path of rapidly revolving hammers. Thence it passes over a screen bar or perforated-plate cage, where all that is sufficiently reduced will pass through, while the remainder is carried around the machine for a second operation. It will accept large-size feed and effect a great ratio of reduction. Units built specially for the purpose will reduce steam-shovel size limestone to  $1\frac{1}{2}$  in. and finer in one operation. In addition, the wide adjustability of hammers and screens permits wide variation in the range of product sizes.

As to resultant product size from dry friable materials, the swing hammer mill will yield a product of approximately 10 mesh; in some cases down to 20 mesh and finer, with from 30 to as much as 80 per cent through 100 mesh. Or it can be

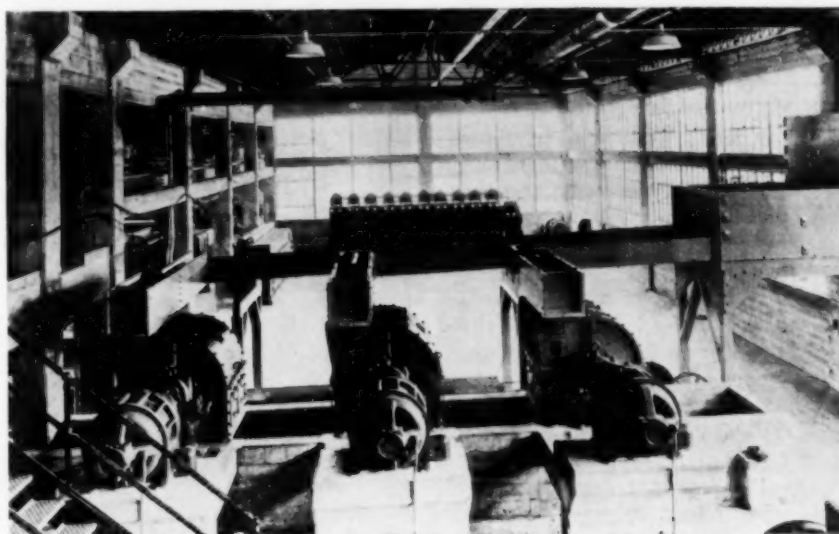


Fig. 1—Battery of swing hammer shredders used in a plant for converting wood waste from lumber mills into insulating board

equipped and operated in such manner as to yield a wide range of sizes anywhere between 2 in. and under and 20 mesh and finer.

Fineness is to a large extent determined by the intensity of the blow, and different degrees of reduction may be had simply by varying the speed of the rotor. For a given bar spacing, more fines are made at high speed than at low speed, generally speaking. Different materials and different conditions of the same material as to temperature and moisture, for example, will show a corresponding difference in the degree of reduction.

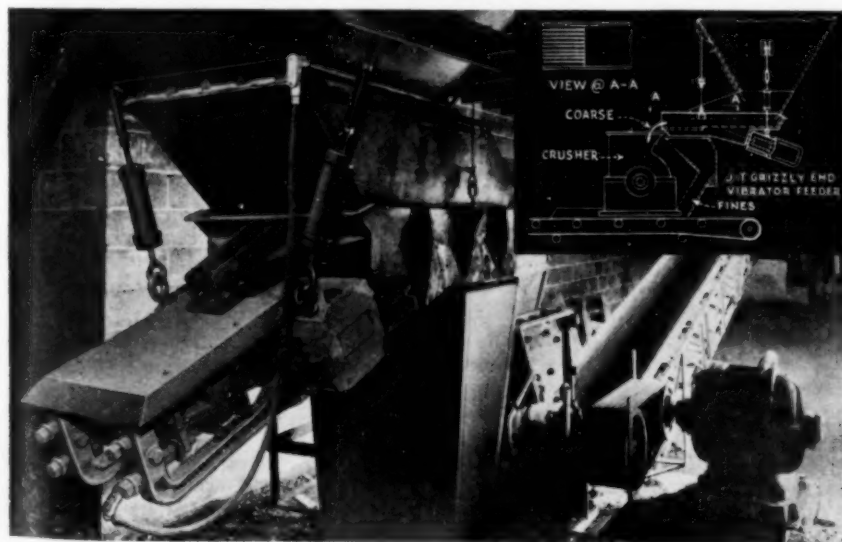
As the swing hammer mill is a high-speed machine, the hammers must be made to balance when shifted or changed. Obviously it is a mistake to make up a set of hammers by indiscriminate combining of new and worn blades. Time is well spent in arranging pairs of the same weight oppositely.

Material containing silica and compounds of similar nature will cause inordinate wear of the exposed parts of any machinery used to reduce them. In the case of a swing hammer mill, the greatest wear is on the hammers and a lesser amount on the screen bars and liners, all of which, of course, are replaceable. Owing to the number of materials this machine is reducing and the variation of product sizes required, it is impossible to indicate accurately the amount of wear to be expected when handling a given material, especially since the condition or character of the material is a factor, whether it is wet or dry, hard or soft.

In connection with wear from silica-bearing materials, a rough yardstick to follow is this: Consider a silica content of 5 per cent or less permissible; 10 to 15 per cent doubtful; 20 per cent dangerous; and over 30 per cent prohibitive in cost in most cases. The safest procedure is to have a chemical analysis made of unusually abrasive materials as a basis for determining the proper method. It is the sure way of avoiding unexpectedly high costs.

Experience has indicated another good rule: When reducing a high-

Fig. 2—An electric vibrating grizzly feeder for scalping feed to a crusher. By-passing of fines keeps size-reduction machines working at maximum efficiency



calcium, dry limestone to a fine product, expect the median cost to be approximately one cent per ton for each per cent of free silica.

Usually a high calcium limestone causes less wear than a dolomite with the same silica content; and the same material when fed to the machine wet causes considerably more wear than when dry. If the openings between the bars are increased, the amount of wear is reduced. Many swing hammer mills are being operated economically on sand rock, flint, boulders, cullet, slag and similar abrasive materials where only a medium reduction is required and the bar openings are large, or where the machine is being operated without bars. Some abrasive materials when wet will more than double the wear on hammers as compared with the same materials when dry.

A requisite of efficient hammer mill operation is a free circulation of air through its orifice, as the machine develops a fan-like action. If the discharge from the hammer mill is blocked, back pressure prevents the reduced material from passing out between the bars and capacity is reduced. This condition is very frequently promoted when an attempt is made to prevent the spreading of objectionable dust by closure at the very outlet of the machine. Sealed discharge to an enclosed elevator, or to a conveyor with an extended covering, serves satisfactorily to correct the dust nuisance.

When reducing wet agglutinative material, care should be taken to see that there is no place for the material to lodge or build up after passing out of the machine. All sides of the chute from the base of the mill should be vertical for such materials. Otherwise the outlet may quickly close up even when no bars are used. A receiving conveyor should not be less than 3 ft. from the base.

The speed of a hammer mill ought never be reduced to the point where centrifugal force fails to keep the hammers out in proper position, otherwise there is danger of damaging the rotating parts. More speed is required to keep the hammers extended when large irregular pieces are fed than for small uniform feed.

It goes without saying, that to get the maximum capacity from a swing hammer mill—or from any other reduction machine, for that matter—a uniform and continuous feed is

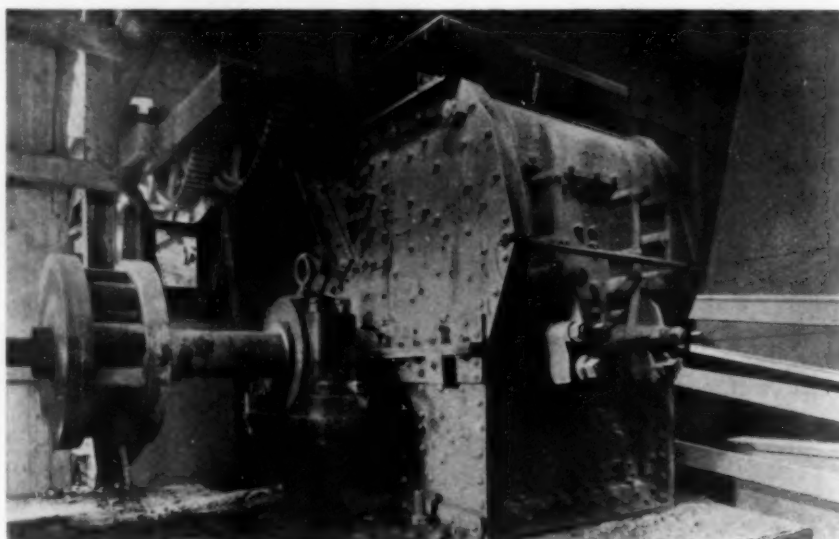


Fig. 3—This giant 54x48 in. swing hammer crusher, operating in a cement mill, takes steam-shovel size limestone and brings it down to  $1\frac{1}{2}$  in. and finer in one operation

necessary. Where accurate sizing is not important, or where full capacity output is not needed, an elevator or belt may be relied on to serve as a feeder. But in most cases discharge from a storage or surge bin is the practice. In these cases a feeder of some type is invariably essential. On some jobs a reciprocating plate feeder or apron feeder may suffice. But an improvement over the use of these can be made by employing a variable control, all-electric vibrating feeder. This feeder obviates the need for regulating gates on the bin openings, automatically controls withdrawal at any rate, and helps prevent arching of material in the bin.

This feeder, furthermore, can be had with a grizzly opening for bypassing fines, which practice is an aid to almost any size-reduction job. Certainly, this scalping is important where reduction facilities are pressed, and/or utmost sizing accuracy is a controlling factor. Only specific conditions will tell whether the bypassing should be from a screen to remove all the fines, or from a grizzly to remove a fair portion of them.

This removal is particularly desirable with the swing hammer mill because this machine reduces by impact and the fines tend to absorb or cushion its shattering blows. If the feed is damp, furthermore, the fines heighten the tendency toward clogging or bedding.

An electric vibrating grizzly feeder shown in Fig. 2 will meet the requirements of the average job. This

unit is not proposed to be a highly efficient screening device, but it will effect the removal of approximately 70 to 80 per cent of fines—say, minus 1 in. from wet material, to as little as minus  $\frac{1}{2}$  in. from dry. At the same time it will do effective feeding, spreading the load over the full width of the reduction unit, thus accomplishing two jobs in one.

Scalping presents a problem where the percentage of fines in the feed varies widely, for then the rate of feed to the size-reduction machine will vary in like proportion. The vibrating grizzly feeder, however, will overcome this difficulty because, being all-electric in operation and having instantly responsive and variable control, it can be interlocked with the power demand of the reduction unit for automatic speed-up or slow-down of the feed, depending upon the amount of fines present. Thus it keeps the size-reduction machine working to its maximum efficiency at all times. Where any great variation in fines comes in surges at fairly wide intervals, hand control of the grizzly feeder will suffice.

For secondary or final size-reduction a grizzly feeder, of course, is not applicable because close spacing of the bars is not effective. The answer here is the use of a screen fed by an all-electric vibrating pan feeder. This pan feeder, like the grizzly feeder, can be tied in with the power demand of the reduction machine to assure it a constant, uniform feed. With or without grizzly,

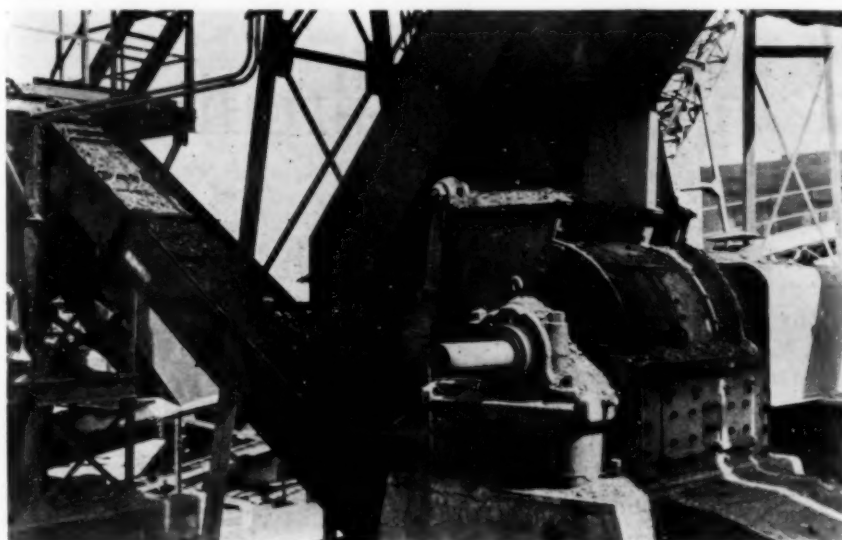


Fig. 4—Latest practice in paper pulp mill calls for shredding of refuse from the barking drums. This permits trouble free, automatic feeding of the refuse furnaces and avoids blow holes in the fuel bed

these feeders may be totally enclosed.

By its very principle of construction and operation, the swing hammer mill is logically suited to shredding of fibrous materials. It produces a uniform product, no great amount of objectionable coarse material from fractions which resist treatment, and no undue amount of dust. It has an advantage also in that by simply changing the speed of the machine, or some part of the assembly, a marked difference may be effected in the character of the shredded product. This adjustability of the machine permits change of product to conform with the experience gained in making it.

Particularly valuable is this flexibility when the material to be shredded varies in character or condition from time to time. Thus knotted wood or damp material will go through a coarser screen, whereas it would plug the finer mesh of bars so successfully used for dry or higher grade material. For some classes of work it may be advisable to have different meshes of bars in different portions of the screen cage. Sometimes it is best to leave a rather wide opening in the rear of the screen cage to allow freer discharge of undesirable remnants of material such as tough, fibrous stems.

As would be expected, there is quite a decided difference between the swing hammer mill used in crushing or pulverizing, and that used in shredding, although in out-

side appearance they may look pretty much alike. The swing hammer shredder, which accomplishes size-reduction by tearing action, or by impact beating or pulping, is equipped either with sharp edged perforated screen plates, or bars. Experience is the best guide, in fact the only guide, in determining the kind of screens, hammers or knives to use on a given material for a given product. Beyond this, it is a case of trial and error. The correct solution is sometimes not easily gotten—an example being the reduction of pine chips in turpentine extraction. In earlier times, the resinous condition of these chips defeated satisfactory operation of shredders in warm weather; it took years of design development before the difficulties were finally overcome.

As with the purely impact type of swing hammer mill, the hammers on the shredder type act the same as do the blades in a centrifugal fan.

The air current created, combined with the radial force imparted to the material by the hammers rotating at high speed, tends to throw the material beyond the reach of the hammers in the feed entrance zone. Unless machine design makes correction for this action, best operating characteristics and results are not always obtained. Too flat an angle to the throat plate in the handling of the denser materials may cause too great an accumulation of material through which the hammers must force their way; again, it may cause an effort-wasting flaying action in the reduction of the lighter materials because insufficient feed keeps within the path of the hammers; or too flat an angle allows wet material to build up out of reach of the hammers. These conditions contribute variously to machine clogging, production of undue fines, needless wear, lowered capacity or increased power consumption.

Sufficient speed and adequate power for continuous uniform operation are prime elements for success with swing hammer shredders. The higher speeds usually cut through the material easier and more uniformly than the lower speeds. Generally, the higher the speed the greater the reduction.

Here, abruptly, we come to the end of a discussion which in parts may raise question and disagreement from some readers, all of which is to be expected because the technique of size reduction is largely empirical. The rules and the experience on one job or on one material cannot always be translated to another, sometimes never. Size-reduction of materials will always remain tricky, and much will always remain to be learned. The writer has been made aware of this by the many vicissitudes encountered in over thirty years of working at it in a wide range of industries.

#### ***DO's and DON'T's in Hammer Mill Operation***

**Don't attempt to make 100 per cent of the specified size if a small percentage of oversize is allowable. An allowance of 2 or 3 per cent oversize adds much to the capacity of a machine.**

**Remove from the feed, material already of the size wanted. This will lower the first cost by allowing use of a smaller machine. Fine material going through a machine increases power consumption and adds to machine wear even if already to specified size.**

**Avoid irregular loads on the swing hammer machine as much as possible. Uniform loads give larger capacities and save power.**

**Feed material into machine with as little fall as possible to get better preparation and less wear on parts.**

# Grinding in Closed Circuit

BY HENRY W. HITZROT, engineer of The Dorr Co., New York, who for the past six years has been engaged in metallurgical work with the Canadian Division of the company. His specialty is classification and fine closed-circuit grinding. Graduated from Princeton in 1924, he took graduate work at Harvard. He is a member of A.I.M.E.

CLOSED-CIRCUITING of grinding equipment is the practice of withdrawing material from the mill before it is completely ground, separating out the material which is already reduced to the desired size, and returning the over-size for further grinding. The method is applicable in both wet and dry grinding, being accomplished by classifiers in the former case, and by screens or air separators in the latter case. Although the present article is concerned with wet grinding only, much that is said will obviously apply to closed-circuiting in dry grinding.

Closed-circuit grinding was developed and brought to its present state of perfection by the metallurgical industry, where it has been in virtually universal use for nearly 30 years. The reasons behind this are quite obvious: the metallurgical industry is concerned with the grinding of heavy tonnages of ore and hence the unit cost of grinding is a large and governing factor in the cost of its finished product. Closed-circuit grinding offered an opportunity to reduce these costs and, as finally developed, has more than justified itself on that score alone, making important reductions in the consumption of grinding power, mill liners and grinding media.

In chemical process industries, on the other hand, closed-circuit grinding has been little used. This is because in most branches of the chemical field the tonnages to be ground are comparatively small and thus, in many cases, closed-circuit grinding could not be proved-in on the basis of savings in grinding power, media, or mill liners, alone.

What this article seeks to point out to process engineers is that hand-in-hand with a reduction in grinding costs, closed-circuit grinding has also brought to the metallurgical industry a closer control of the particle size of its ground product than can be obtained by any other method of wet grinding. With modern industrial processes increasing the demand for close control of particle size in grinding operations, this feature should lead to a wider application of closed-circuit grinding than has heretofore been the case in the chemical industry. At the same time, the opportunity afforded by the closed-circuit method to reduce unit grinding costs should not be overlooked when these costs are an important part of the total processing cost.

## Closed vs. Open Circuit

Open-circuit grinding is that method which aims to secure the desired size-reduction by a single passage of the material through the grinding mill. Unfortunately, to secure a finished product that will not contain material greater than a certain sieve size, the material to be ground must remain in the mill until every particle has been reduced to the size specified. Hence, the greater portion remains long after it has reached the fineness desired and, as a result, is ground not only finer than necessary but often finer than desirable or even permissible, for the subsequent process. Also, there is unnecessary consumption of power, mill lining and grinding media.

An inherent defect of open-circuit grinding is that the minimum size of particle cannot be controlled. Nearly

the same objection may be made to batch grinding. Furthermore, in actual practice, it is found that even the regulation of oversize in open-circuit grinding is not what it should be for a carefully sized product. Changes, beyond the control of the operator, in hardness and fineness of the raw material and in the rate at which the material is fed to the mill will inevitably lead to the occurrence of stray oversize particles in the final product.

In grinding with a classifier closed-circuited with the grinding mill the oversize portion of the mill discharge which is returned to the mill by the classifier is called the circulating load and may profitably be built up to several times the new feed to the mill. An important feature of this set-up is that the control of the particle size is centered at the classifier and not at the mill. The classifier automatically takes care of small fluctuations in hardness, coarseness, and rate of feed to the mill. In addition, it permits the grinding mill to be fed at such a rate and loaded in such a manner that in the case of continuous and large scale grinding, large savings are effected in power, wear on mill liners and wear on grinding media.

Equipment used in closed-circuit grinding has been standardized to a great extent and in a typical layout consists of a cylindrical wet grinding mill, a classifier, and two launders, the one conveying the mill discharge to the feed end of the classifier and the other conveying the oversize discharge from the classifier to the feed box of the mill. The mill is generally equipped with a scoop

feeder which picks up new feed and classifier discharge, feeding the mixture into the mill through the hollow feed trunnion together with sufficient water to bring the feed to the proper moisture content for efficient grinding. The classifier overflows a uniformly fine finished product, suspended in several times its weight of water.

It has already been pointed out that the circulating load may profitably be built up to several times the new feed to the mill. That being the case, the question is frequently asked, "What circulating load ratio should be carried?" This is really an ambiguous question and one that will lead to great difficulty if not properly considered. What is actually required for good grinding is a proper loading of the mill. To bring this about there should always be added to the new feed the correct amount of circulating load from the classifier to give the optimum tonnage through the mill. When the problem is considered in this manner, it takes on a new aspect, as the following will show:

In every grinding unit there is available an effective volume through which feed will pass, which, if properly utilized, will lead to maximum capacity. However, if the tonnage of total feed becomes excessive for the total volume then the mill will "choke." Changing the dilution of the pulp in the mill will not remedy the congestion, for the available mill

volume has been taxed beyond capacity, and the stoppage is due to overloading.

Thus, as data from actual practice have proved, the total tonnage of feed through the mill and not the circulating load ratio is the important consideration in obtaining best efficiency from closed-circuit grinding. Concerning actual mill loadings, a review of several important grinding applications which used the heavy duty Dorr classifier in the circuit has shown that the total tons of feed to the grinding unit has fallen in the range of 14 to 20 tons per day per cu. ft. of mill volume.

**Size Control**—Increasing recognition is being given to the fact that in many cases the utility of a finely ground product is dependent upon not one, but two things. These are: first, its degree of subdivision and second, the size distribution of its particles. In other words, it is not enough to specify simply that a product be ground to, say 90 per cent minus 200 mesh. Several samples of the same product may all pass 90 per cent through a 200-mesh screen; yet if not ground under exactly the same conditions, may have entirely different distributions of particle sizes. Hence, there may be widely varying characteristics in the aggregate.

As a rule, a properly adjusted closed-circuit system comes nearer to producing the mesh distribution desired than any other method. This

is true because the closed-circuit system allows us to "bunch" the grind. For example, if we wish to grind a 1/4-in. feed to 97 per cent minus 200, open-circuit grinding will produce a much greater quantity of this as minus 325 mesh superfines than will closed-circuit grinding. At the same time, there will certainly be considerably more plus 150-mesh material in the open-circuit product.

**Fineness of Grinding**—The operating data tabulated below are from the portland cement industry and give a comparison of size distributions and fineness of grinding obtained by grinding in open- and closed-circuit. At the plant where these results were obtained a year's operation with open-circuit grinding gave an average fineness of 89 per cent minus 200 mesh and 5 per cent plus 100 mesh. Under closed-circuit conditions the average fineness has been increased to 97.5 per cent minus 200 mesh and nothing on 100 mesh, while at times, when handling only 50 tons per hour per mill, the fineness has been held at 99.9 per cent minus 200 mesh and 95 per cent minus 325 mesh.

The table below shows the distribution of sizes as determined by screen analyses, elutriation tests and microscopic examinations of particle sizes.

Table I—Comparison of Size Distribution

Sieve No.	Mesh	Open-Circuit		Closed-Circuit	
		% +	% Cum.	% +	% Cum.
1.....	20	1.0	1.0	....	....
2.....	28	0.25	1.25	....	....
3.....	35	0.50	1.75	....	....
4.....	48	0.50	2.25	....	....
5.....	65	0.75	3.00	....	....
6.....	100	2.00	5.00	....	....
7.....	200	6.00	11.00	2.6	2.6
8.....	325	(not recorded)		8.4	11.0
Elutriation Jar					
1.....	340*	10.7	21.7	16.6	27.6
2.....	540*	7.8	29.5	5.9	33.5
3.....	820*	3.4	32.9	6.7	40.2
4.....	1400*	8.4	41.3	8.0	48.2
Overflow.	....	58.7	....	51.8	....

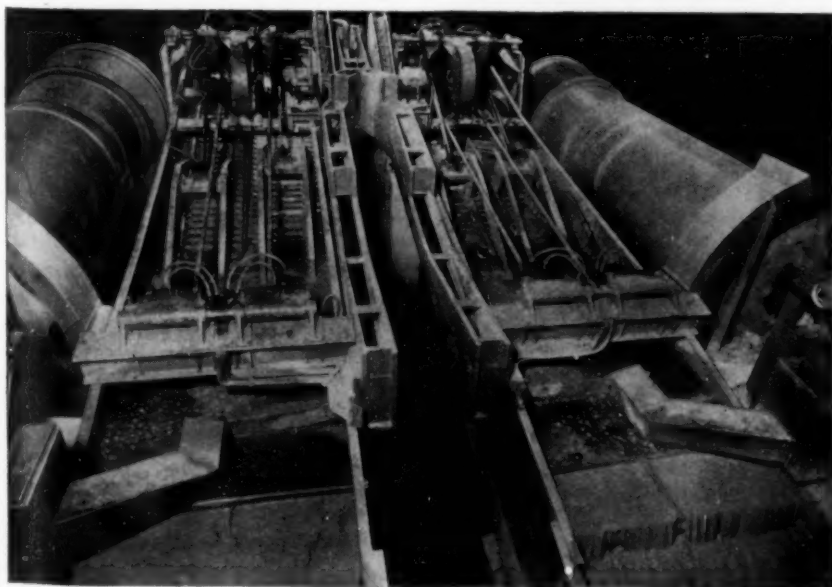
\*Average particle size determined by microscopic examination.

A study of these particle size determinations indicates: (a) An elimination of stray oversize, coarser than critical size; (b) a substantial reduction in plus 200 mesh material; and (c) less superfine as indicated by final elutriator overflow.

Another size analysis that shows how the substitution of closed-circuit for open-circuit grinding results

(Please turn to page 243)

Classifiers in closed circuit with tube mills at a metallurgical mill. Particle size of the tube mill product is automatically governed by these classifiers



# Low-Temperature Grinding

BY S. B. KANOWITZ, who for the last 20 years with the Raymond Pulverizer Division of Combustion Engineering Company, Inc., has specialized in the application of pulverizing and air separating equipment for the chemical and mineral industries.

JOHN MASURY obtained patents in 1870 and 1872 on the first water-cooled stone mill ever made. This increased by 15-fold the production of the uncooled mills then used for pulverizing coach black in japan enamel. Around 1885 or 1886 Robert Kent started to build water-cooled mills of a conical type for fine color grinding. Shortly after the designs for these mills had been perfected, the water cooling of larger mills—some as large as 36 in. in diameter—was attempted. It was found that these mills could be operated at higher speeds than the uncooled mills, and hence the production capacity was materially increased.\*

The commercial importance of even moderate cooling has increased remarkably since those early days. Also, the range of cooling has been extended very materially during the past few years to the sub-atmospheric temperature regions. This use of sub-atmospheric cooling temperatures is today an increasingly important economic factor in the pulverization of many types or classes of materials.

There are many advantages of pulverizing at sub-atmospheric temperatures. Among these may be mentioned the following:

1. At atmospheric temperatures or slightly above some materials are sticky or plastic and tenaciously resist reduction to a powder.
2. Materials which contain water of combination and tend to give off this water at a slight increase in temperature can be pulverized safely in a cold atmosphere.
3. Although certain materials may be ground at ordinary temperatures, a much greater capacity may often

be obtained when these materials are pulverized at low temperatures—in other words, we can obtain increased capacity at given fineness, or increased fineness at given or increased capacity.

4. When materials become chemically unstable or tend to oxidize at a comparatively small increase in temperature, sub-atmospheric cooling is often most effective.

There are several methods in use for producing the sub-atmospheric temperatures. Some of the more important of these are listed below:

1. Cooling the material prior to pulverization. The material is either kept in what is known as a "cooling box" until it reaches the required temperature or is brought to the pulverizing equipment in a continuous conveyor which is enclosed in an insulated trough or housing lined with cooling coils.
2. The pulverizers are jacketed to permit the circulation of brine or a refrigerant.
3. The material is pulverized and conveyed in a current of cooled air.
4. Dry ice, liquid air or similar very cold liquid may be mixed with the material to be pulverized. Carbon dioxide, used particularly in jaw crushers and ball mills, has the added advantage of automatically creating an inert atmosphere.
5. Often a combination of the above systems is employed depending upon the nature of the material and the results to be obtained and on the economy of the operation.

The cost of refrigeration should, of course, be balanced against the reduction in the cost of grinding the cold material. There is often a considerable increase in capacity with a corresponding decrease in power consumption per unit of material ground. Even if the extra cost of refrigeration does not overbalance the economies obtained in grinding, it may often be advantageous to use refrigeration with some materials which, particularly in the summer months, can only be ground with the greatest difficulty.

When grinding many materials without cooling, the pulverizing apparatus has to be shut down, opened up and cleaned out rather frequently. This not only causes loss of time but often ruins a considerable amount of material.

When hot, humid air is cooled, much of its moisture is precipitated before it enters the pulverizer. In passing through the pulverizing and conveying system the temperature of the refrigerated air will be elevated and its relative humidity lowered but in this case there is no danger of adding moisture to the product while it is being conveyed to the containers. When refrigeration is not used, humid air may precipitate its moisture in the containers causing the material to lump. This is often serious in the case of hygroscopic materials such as sugar, citric acid and many other organic crystals.

The types of equipment generally used for pulverizing materials at low temperature include the ball or pebble mill, the hammer mill with screen or air separation and the ring-roll mill with air separation. When the ball mill is used for this purpose it is equipped with a jacket through which brine or cold water may be circulated. This also applies to the jacketed hammer mill with screen separation.

Fig. 1 shows a screen pulverizer with jackets in which the cooling medium circulates. It will also be seen that the screen on the bottom is so designed that the cooling medium may be circulated through it. This is often of advantage when handling materials which tend to build up on a warm surface.

When using jacketed pulverizing equipment, care must be taken that air entering the pulverizer and com-

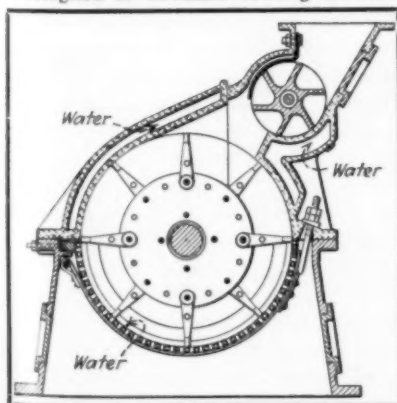
\* See Section 16, "Crushing, Grinding and Pulverizing," Perry's "Chemical Engineers' Handbook," pages 1555 to 1640. The author also wishes to express his appreciation to Dr. Perry for having suggested the field for this article and for supplying these historical references.

ing into contact with the cold surfaces is not cooled below its dew point since this would precipitate moisture in the pulverizing chamber. It is partly for this reason that even when screen mills are used, refrigerated air is circulated through the mill used for conveying the pulverized product. The main reason, however, is that generally with this type of machine there is not sufficient time for cooling the material during the time interval it is within the pulverizing chamber, particularly when it is necessary to cool the product considerably below atmosphere. The screening surface must necessarily be limited in the amount of cooling surface exposed and although, as mentioned above, it performs the beneficial function of preventing the material from building up, it cannot absorb sufficient heat to do much cooling. One finds a different situation with the ball mill. Here considerable cooling surface is exposed to the material which takes a comparatively long time to travel from the feed to the discharge end. More precautions must be taken with this type of mill that air entering the mill is not cooled below the dew point. However, this type of mill can also be air-swept effectively with cooled air.

The results obtained with a hammer mill equipped with a jacket through which brine is circulated, are shown in the following table:

Material .....	Cocoa (26 per cent butter fat)
Amount of cocoa entering mill.....	500 lb. per hour
Fineness .....	90 per cent through 200 mesh
Temperature of the cocoa entering mill.....	82 deg. F.
Temperature of the cocoa leaving mill.....	77 deg. F.
Temperature of the brine entering pulverizer .....	17 deg. F.
Temperature of the brine leaving pulverizer .....	23 deg. F.

Fig. 1—Jacketed screen pulverizer designed to circulate cooling medium



Pounds of sodium chloride brine circulated ..... 3400 per hour  
Power consumed..... 6 kw.-hr.

The same type of pulverizer is used for pulverizing zinc stearate. In this particular installation the pulverizer was jacketed but cold air was used for conveying the product from the pulverizer to the packaging department, with results as follows:

Nature of material.....	Zinc Stearate
Amount of material fed to pulverizer.....	300 lb. per hour
Temperature of material entering pulverizer .....	90 deg. F.
Temperature of material leaving air system .....	70 deg. F.
Power consumed.....	10 hp.
Refrigerant .....	Sodium Chloride brine (10 per cent by weight)
Temperature of brine entering cooling system .....	16 deg. F.
Temperature of brine leaving cooling system .....	40 deg. F.
Temperature of air entering cooler.....	90 deg. F.
Temperature of air leaving cooler.....	46 deg. F.
Amount of brine circulated .....	10,500 lb. per hour
Quantity of air leaving cooling system.....	1000 cu. ft. per min.
Temperature of air leaving pulverizing system .....	62 deg. F.

In an air separator pulverizer in which refrigerated air is passed directly into the grinding equipment, it is often desirable to circulate brine through an outside coil or a similar type of heat exchanger. Air is passed over the cooling surfaces and introduced directly into the pulverizer. More efficient heat transfer is obtained by spraying the brine into the cooling chamber through which the air passes. Before entering the pulverizer the air passes through a water separator for removing any entrained water. The pulverizer may be of the hammer type or of the ring-roll type equipped with air separation. In this type of unit the material, as in the standard air separator mill, is conveyed by the air to a cyclone collector where the pulverized material is discharged. Instead of returning to the pulverizing system, the air is first passed through a filter to remove any dust it may contain. The clean air then passes to a refrigeration system where it is cooled to the proper degree and then introduced to the pulverizer. Since most of the air is used over and over again, economy of refrigeration is greatly increased.

The results obtained on a ring roll mill when grinding and cooling a synthetic resin are given below:

Amount pulverized per hour....	2000 lb.
Fineness of finished product.....	98 per cent 200 mesh

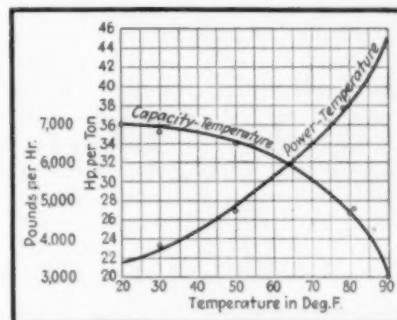


Fig. 2—Lowering temperature increases capacity and reduces power in grinding a synthetic resin

Temperature of resin entering mill .....	90 deg. F.
Temperature of air leaving cooler and entering mill.....	20 deg. F.
Temperature of air leaving mill and entering cooler.....	50 deg. F.
Total power consumed.....	26 kw.-hr.
Temperature of resin leaving system .....	57 deg. F.
Amount of air leaving cooler and entering mill.....	2200 cu. ft. per min.

It is often necessary not only to pulverize some materials at sub-atmospheric temperatures but also to have the material remain at a constant temperature. This may be done by means of a thermostatic control. Cold and warm air come from two sources into a common duct which leads into the pulverizer. Whenever the temperature at any predetermined point in the system changes, the control automatically varies the proportions of the warm and cold air entering the pulverizing system.

There are certain materials, such as cocoa powder, which must be pulverized at a low temperature to obtain most efficient pulverizing operation. On the other hand better color or other physical characteristics are obtained if the material is heated and chilled. The cocoa is pulverized in a cold atmosphere and then passed through a heater box which gradually brings the temperature up to a predetermined point. The material is rapidly chilled by dropping it into a stream of refrigerated air. The product then goes to an air separator and the finished product is removed. Cold air is also introduced into the air separator in order to prevent a temperature rise. The proper temperatures are maintained by thermostatic control.

The graphs in Fig. 2 show the great increase which may be obtained by grinding a certain synthetic resin at sub-atmospheric temperatures. The material was first cooled in a cooling box prior to pulverization and cold air introduced to keep the material at the initial temperature.

# Jet Pulverizing Now Practical

BY MARCEL A. LISSMAN, consulting engineer for the International Pulverizing Corp., Camden, N. J., who has for a number of years been associated with the development of the theory and design of high efficiency inertial type dust collection devices. Many engineering phases of the Micronizer development have been in his hands.

FOR MANY YEARS dry grinding in the sub-sieve range (625 to 2500 theoretical mesh) has usually been commercially impractical and possible only at high cost. Consequently, much work has been directed toward developing a pulverizer designed specifically for this type of grinding. An answer to the problem has now come in the form of a jet pulverizer called a Micronizer.\* It utilizes a shallow circular grinding chamber (see cut) wherein a circulating charge is acted upon by a number of gaseous fluid jets issuing through orifices spaced around the periphery of the chamber. In commercial installations air under pressures of the order of 100 lb. per sq.in. is applied to the jet orifices when grinding materials which will not stand exposure to the temperatures obtained with superheated steam. Most applications, however, utilize superheated steam at pressures from 100 to 500 lb. per sq.in., and temperatures from 500 to 700 deg. F. The grinding chambers commercially used vary from 12 in. to 36 in. in diameter and from 1 in. to 2½ in. in axial height at the periphery. Capacities up to 2,000 lb. per hr. have already been reached commercially.

Jet orifices are drilled through the peripheral wall of the grinding chamber and vary in number from 6 to 16 equally spaced around the chamber, and in size from about ⅛ in. to ¼ in. They are drilled in such a direc-

tion that the issuing jets of fluid will all promote rotation of the contents of the grinding chamber in the same direction. The axes of the jets are all tangent to a common circle concentric with the grinding chamber and of smaller diameter. Size of the circle selected may depend upon the particular grinding problem to be solved in a given installation.

## How It Works

In operation, the jets introduce fluid streams of high energy content into the small pulverizing chamber, the applied fluid pressure being transformed into velocity head by expansion to substantially atmospheric pressure within the grinding chamber. Application of these jets of fluid causes a high-speed rotation of the contents of the chamber, which con-

sists of a relatively small circulating load of material being acted upon and entrained in the gaseous fluid. Radial acceleration resulting from the high rate of rotation causes the circulating load to concentrate adjacent to the periphery of the chamber where the high velocity fluid jets are introduced. Most of the energy of the fluid jets is dissipated within an inch or two of the point of entry, causing intense local velocity gradients and violent interactions within the circulating material. Observations indicate that most of the reduction is independent of any interaction with the confining walls of the chamber. Naturally, wear is experienced in operation, and may present a serious problem for particular applications. However, very successful applications have been made with a rubber-lined grinding chamber without any noticeable reduction in grinding efficiency over an unlined chamber, indicating that wall reactions are only incidental in operation.

The gaseous fluid supplying the grinding energy is withdrawn at an inward point through an opening concentric with the grinding chamber. Thus the supplied fluid is caused to spiral inward from the periphery of the grinding chamber to the outlet. In operation, the supply of fluid to the chamber from either an air compressor or a boiler is kept constant, thus keeping the radial component of fluid flow constant. This inward component of fluid flow produces an intense sweeping action upon the circulating load of the grinding chamber, causing the removal of material

Surveying the field for completely new departures in grinding, *Chem. & Met.*'s editors recalled the frequent but uninformative rumors that have been current in recent years regarding the new jet-pulverizing Micronizer. Introduced with a minimum of fanfare, it has never been described in detail outside its patent specifications. Consequently, this is the first complete article to appear on the subject.

\* Name registered in U. S. Patent Office. Invention covered by U. S. Patent No. 2,032,827, March 3, 1936, to Norwood H. Andrews, assigned to International Pulverizing Corp., Camden, N. J.

as soon as it reaches the size desired in the product, together with the smaller sizes generated by chance fractures.

Since the manner of application of the grinding energy causes the contents of the chamber to rotate rapidly, an intense centrifugal classifying action prevails inside the grinding zone. The intensity of the classifying action is controlled commercially by varying the circulating load within the grinding chamber, which, in turn is readily accomplished by changing the rate of feed. In operation, the pitch of sound gives a rough indication of the rate of whirling of the chamber contents, a high pitch corresponding to a high rate of whirling. Substantially all applications classify the ground material in the sub-sieve range, mostly minus 625 theoretical mesh, or below 20 microns. Most of the applications are minus 1,250 mesh, or 10 microns, and a number are minus 2,500 mesh, or 5 microns.

In practically every installation, the outlet from the grinding chamber leads directly into a concentric centrifugal collector, having a diameter about one-third that of the grinding chamber and an outlet about one-

half the diameter of the collector, as shown in the accompanying line cut. When so placed, the collector does not need any additional means to impart rotation to the fluid stream, as the whirling energy required for centrifugal classification is directly available for centrifugal collection. In practice, the collection efficiency increases with the intensity of classification, so that the degree of collection usually increases with decreasing particle size in the product. From 85 to 98 per cent of the product is retained in the concentric collector of the pulverizer itself.

#### Feed Injector

An injector operating on the principle of the aspirator is utilized to introduce the feed into the outer portion of the grinding chamber. It is not desirable to feed material which is too fine when this can readily be avoided, as it has been observed that a top size of  $\frac{1}{8}$  to  $\frac{1}{4}$  in. does not lower the capacity of the machine and has been found beneficial in a number of applications. Thus, the Micronizer operates under conditions where  $\frac{1}{8}$  in. material is fed at the periphery of a circular grinding chamber and a product below 5 microns, or 2,500 theoretical mesh, is withdrawn and collected at an inward point near the center.

In addition to grinding, classifying and collecting in the sub-sieve range, this new jet pulverizer has found application in the heat treatment or calcining of material simultaneously with grinding by controlling the temperature of the superheated steam supplying the grinding energy. In connection with compressed air installations the refrigerating effect of adiabatic expansion has been utilized to control the maximum temperature in the grinding chamber regardless of the total energy required for grinding. During expansion some of the heat content of the fluid is changed to kinetic energy. After dissipation of this kinetic energy within the grinding chamber, the fluid cannot attain a temperature which exceeds its initial temperature. Then, due to the intense fluid sweeping within the grinding chamber, the temperature of the material acted upon cannot exceed the initial temperature of the gaseous fluid.

Another field of application incidental to the use of the Micronizer is thorough blending of dry materials, usually associated with some sub-

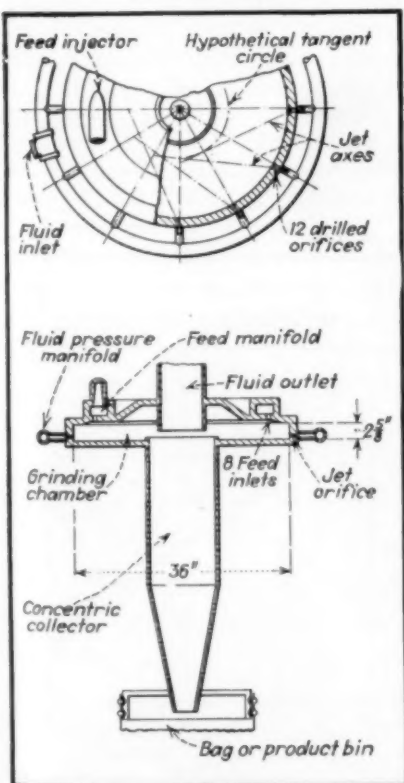
sieve grinding. To illustrate, assume a mixture of dry materials which is to be ground to a size substantially all below 5 microns: As a grinding and classifying problem this requires that no particles or agglomerates larger than 5 microns can on the average successfully run the gauntlet of the classification requirement. Actually, the rate of dissipation of energy in the grinding zone is so high that homogeneous solids larger than 5 microns are shattered, so that agglomerates larger than 5 microns have practically no chance to survive without being dispersed to their ultimate particle size. If this ultimate size is below 5 microns, then the particles are immediately floated off with the product. Upon being collected, the particles will arrange themselves in a perfectly random manner, giving a thoroughly blended product.

Materials to which the new pulverizer has been successfully applied include insecticides and fungicides, pigments, mineral fillers for paper, paint and rubber, cosmetics, various organic chemicals and synthetic resins.

#### Product Has New Properties

The problem of applying the machine to a new commercial field readily resolves itself into two parts: First, the problem is one of design with respect to the physical characteristics of the material to be reduced in order to determine the optimum energy requirements for a product corresponding to various top sizes. Most applications, having a top size requirement in the range from 20 microns to 2 microns, require an energy consumption in the range from 1 lb. to 10 lb. of steam per lb. of product. Second, a new commercial development consists in determining the commercial value of the product, and its potential field of application. In the case of the Micronizer, a new type of product is developed. It has been found that ordinary materials when reduced to this ultra-fine state exhibit entirely new properties. Hence, an extended commercial experimental program must be followed to determine their field of application. To encourage such experimental programs, the Micronizer is not sold to the trade. As new fields of application are developed, the use of the machine is licensed for the various fields; and under certain conditions exclusive licenses have been granted for particular applications within given territories.

Cross-sectional view of a jet pulverizer used for grinding in the range between 625 and 2,500 theoretical mesh



# Grindability vs. Mill Capacity

AN EDITORIAL REPORT based on the work of R. M. Hardgrove, design engineer for The Babcock & Wilcox Co., New York, whose work on grindability tests has been outstanding.

**G**RINDABILITY is that characteristic of a substance which determines the capacity of a given pulverizer for reducing the material to a standard fineness. Numerically it is directly proportional to the specific gravity and inversely proportional to the crushing resistance. Grindability is useful principally in estimating pulverizer capacities and power requirements.

Determinations of grindability are made by a number of methods, two of which have been adopted as tentative standards for coal by the A.S.T.M.<sup>1</sup> These are the Bureau of Mines<sup>2</sup> method and the Hardgrove<sup>3</sup> method. The former method makes use of a ball mill equipped with ribs to prevent slippage. Grinding is done in eight or nine stages with fines removed after each stage, although the charge is not "sweetened" by the addition of more raw material. Later revisions in the A.S.T.M. tentative standards allow use of a shorter proximate method consisting of four stages for certain cases.

The Hardgrove method makes use of a special ball and race type mill with a standard weight (64 lb.) on the balls. The machine is equipped with an automatic revolution counter which stops it after exactly 60 revolutions. Therefore, the grindability of a material is easily determined by weighing out a 50-gram sample, placing it in the machine for 60 revolutions and screening the product. The Hardgrove grindability index =  $13 + 6.93 W$ , where  $W$  is the weight in grams through a 200-mesh sieve. This straight-line relation, determined by 550 tests, has greatly simplified the operation by eliminating many of the testing sieves required.

Numerous materials have been tested by this method, results for some 200 of which have been tabulated in a recent paper by Hardgrove.<sup>4</sup> The tabulation indicated that grindability may vary all the way from 2 to 204 and that the grind-

ability of a single substance may vary considerably depending on the place of origin. In addition a comprehensive list of the grindabilities of coal has been published by The Babcock & Wilcox Co.

Some typical grindabilities of various ores and chemical process raw materials are as follows:

Alum .....	67
Barytes .....	120
Bauxite .....	56
Borax .....	73-143
Cellulose Acetate .....	7
Chrome Ore .....	45-55-56-70
Clay .....	74-135
Dolomite .....	112
Feldspar .....	43
Fluorspar .....	92
Graphite .....	51
Ilmenite .....	43
Kieselguhr .....	132
Lime .....	105-135
Mica .....	7
Oyster Shells .....	59-63
Phosphate, Tri-Calcium .....	134
Quicklime .....	138-180
Resin, unground synthetic .....	14
Rosin .....	175
Rutile (TiO <sub>2</sub> ) .....	26
Salt .....	54
Sand, silica .....	24-50-55
Shale .....	37-204
Slag .....	32
Sulphur, raw .....	90-104-134
Talc .....	67-70-74-84-121-125-130
Zinc Blende Ore .....	136
Zinc Oxide .....	96-103

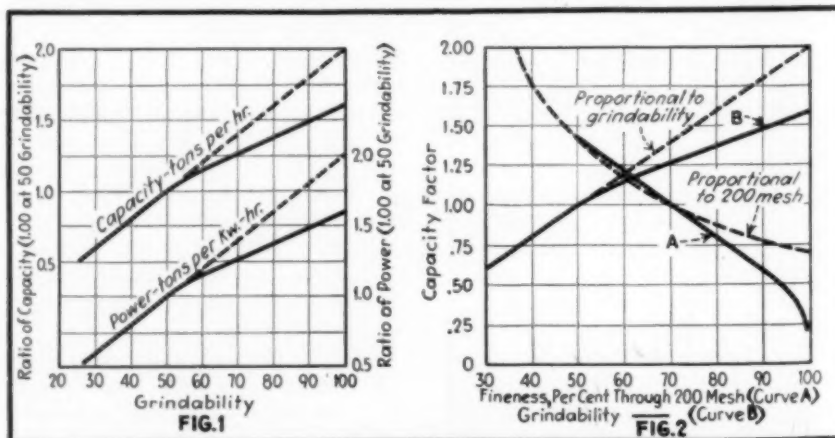
Fig. 1 is a summary of a number of curves reduced to a common capacity basis showing the relation of grindability to capacity and to power requirement of a coal pulverizer. These curves are applicable to any size pulverizer because the characteristics are similar throughout. It is obvious that capacity is directly proportional to grindability in the lower range (30-55), but at higher grindabilities capacity falls below the proportional line. This is due to the cushioning effect of material finer than 200 mesh which has not been removed from the grinding area. It has been found, however, that if less than 25 per cent of the material around the balls is finer than 200 mesh, no appreciable cushioning occurs. Therefore, in efficient closed-circuit systems, which have thorough fines-removal, capacity may be maintained proportional to grindability in the higher grindability range.

Power required to drive a pulverizer at full load is, as demonstrated by the lower curve in Fig. 1, practically constant for all grindabilities, delivering a product of the same fineness. Note that power is expressed in tons per kw.-hr. instead of the reverse, in order to show the similarity to the capacity curve.

In connection with Fig. 1, it should be emphasized that the data plotted are representative only of a specific type of mill. Other types show a somewhat different relation between capacity and grindability as pointed out by Frisch.<sup>4</sup>

Grindability is not the only factor affecting mill capacity. Fineness also plays a part, as shown in Fig. 2. Thus to find the capacity of a pulverizer for (Please turn to page 285)

Fig. 1—Average performance curves for five sizes of ball and race pulverizers  
Fig. 2—Effect of grindability and fineness on the pulverizer capacity factor



# Pulverizing 200 Process Materials

A TABULATION of the answers of 43 manufacturers of pulverizing equipment when asked "Which of these materials has been successfully ground in a plant installation by your equipment?"

IN AN EFFORT to present factual information regarding methods of crushing, pulverizing and grinding specific materials used in the process industries, the editors of *Chem. & Met.* appealed to manufacturers of such equipment with a questionnaire. A preponderance of the industry is represented in the 43 replies (names, addresses and types of equip-

ment made are shown below). All data thus received have been carefully consolidated into the accompanying table. However, before proceeding directly to the table, a few explanatory remarks are in order.

First of all, the editors have made no attempt to analyze or edit the results. Secondly, no attempt has been made

to give quantitative results. In other words, whether one or ten companies indicated the use of a certain type of machine for a certain job, has not been considered.

The reader should be warned that all results may not necessarily be acceptable at their face value. For instance, if it is indicated that one type of machine will perform a certain task, it does not necessarily follow that all machines of the same type will do the same job. Nor does it follow that a type of mill not mentioned may not be the best solution to a particular problem.

Equipment has been classified by the grinding principles involved according to the best information available.

Particle sizes indicated as column headings on the table refer to the product size for the machine in question. Types of equipment, both in the table and after the manufacturer's names, are indicated by reference letters, the key to which is given below.

## Cooperating Equipment Manufacturers

ABBE ENGINEERING CO.	New York, N. Y.	jl n	OLIVER MACHINERY CO.	Grand Rapids, Mich.	g
ABBE, INC., PAUL O.	Little Falls, N. J.	jl ns	PALMER-BEE CO.	Detroit, Mich.	f
ALLIS-CHALMERS MFG. CO.	Milwaukee, Wis.	abefinoqs	PATTERSON FOUNDRY & MACHINE CO.	East Liverpool, Ohio	ft n x
AMERICAN PULVERIZER CO.	St. Louis, Mo.	ij	PATTINOS, INC., GEO. F.	Philadelphia, Pa.	k
BARCOCK & WILCOX CO.	New York, N. Y.	v	PIONEER ENGINEERING WORKS, INC.	Minneapolis, Minn.	afft
BARTLETT & SNOW CO., C.O.	Cleveland, Ohio	efgimn	PRATER PULVERIZER CO.	Chicago, Ill.	ijl
BRADLEY PULVERIZER CO.	Allentown, Pa.	p	PULVERIZING MACHINERY CO.	Roselle Park, N. J.	i
CHEMICOLLOID LABORATORIES, INC.	New York, N. Y.	w	RATMOND PULVERIZER DIVISION,		
DIXIE MACHINERY MFG. CO.	St. Louis, Mo.	ij	COMBUSTION ENGINEERING CO., INC.	Chicago, Ill.	iqu
EPPENBACH, INC.	Long Island City, N. Y.	w	ROBINSON MANUFACTURING CO.	Muncy, Pa.	ghijklq
GRUENDLER CRUSHER & PULVERIZER CO.	St. Louis, Mo.	afijlp	SEDERBERY, INC., J. B.	New York, N. Y.	ij
HARDINGE CO.	York, Pa.	no	SMITH & CO., F. L.	New York, N. Y.	np
HURRICANE PULVERIZER CO.	Chicago, Ill.	x	SMITH ENGINEERING WORKS	Milwaukee, Wis.	abdf
JEFFREY MFG. CO.	Columbus, Ohio	aei	SPROUT, WALDRON & CO.	Muncy, Pa.	ehlgat
KENNEDY-VAN SAUN MFG. & ENG. CORP.	New York, N. Y.	abfino	STOKES MACHINE CO., F. J.	Philadelphia, Pa.	x
KENT MILL CO.	Brooklyn, N. Y.	p	STURTEVANT MILL CO.	Boston, Mass.	afgip
LANCASTER IRON WORKS, INC.	Lancaster, Pa.	aff	TRAYLOR ENGINEERING & MFG. CO.	So. Allentown, Pa.	abefn
MANTON-GAVLIN MFG. CO.	Everett, Mass.	w	UNIVERSAL ROAD MACHINERY CO.	Kingston, N. Y.	a
McNALLY-PITTSBURGH MFG. CORP.	Chicago, Ill.	defh	VULCAN IRON WORKS	Wilkes-Barre, Pa.	ein
MINE & SMELTER SUPPLY CO.	Denver, Colo.	ano	WHITING CORP.	Harvey, Ill.	kr
MUNSON MILL MACHINERY CO., INC.	Utica, N. Y.	ist	WILLIAMS PATENT CRUSHER & PULV. CO.	St. Louis, Mo.	eip
NORDBERG MANUFACTURING CO.	Milwaukee, Wis.	c	WOLF CO.	Chambersburg, Pa.	elq

## Types of Disintegration Equipment

<b>Coarse Crushers:</b>	<b>Intermediate Pulverizers:</b>	<b>p. Ring roll</b>
a. Jaw	i. Conventional hammer mills	q. Roller
b. Gyratory	j. Special hammer mills	r. Table roller
c. Cone	k. Impact beater mills	s. Plate or disk attrition
d. Special cone	l. Rotary and knife cutters	t. Buhrstone
e. Single roll	m. Cage mill disintegrators	u. Bowl
f. Double roll (or crushing rolls)	n. Grinding Mills:	v. Ball and race
g. Rotary*	n. Ball, pebble, and tube	w. Colloid
h. Saw-tooth and pick-breaker	o. Rod	x. Other (coffee, pan, etc.)

\* Rotary crusher consists of a vertical rotating shaft carrying a cone with graduated teeth, operating on the same principle as the ordinary coffee grinder.

† Indicates a special variation of the particular type of equipment designated.

Material	Coarse (Down to 1/4 in.)	Intermediate (1/4 in. - 40 mesh)	Fine (Under 40 mesh)
Abrasives.....	abedefij	defjnopr	dnopr
Acetanilid.....	ei	eikrs	ijkprs
Acetate of lead.....	i	ikrs	ijkrs
Aloxite.....	aij	ino	jn
Alundum.....	ai	finop	jnp
Alum.....	cehij	ijkklrs	ijklpqrs
Alumina.....	abej	efjlnops	jlnpqs
Aluminum.....	aij	efir	npr
Aluminum Silicate.....	acefht	ikrsx	jknprsx
Aluminum Sulphate.....	hij	ijkrs	ijkrs
Ammonium Nitrate.....	eij	ijkrs	ijkrs
Ammonium Sulphate.....	efhij	ijkrs	ijkrs
Andalusite.....	i	imor	jnr
Asbestos.....	abedefghijln	efijlms	ijlmps
Arsenate of Lead.....	i	ijkpr	ijkprw
Asphalt.....	abeehij	efijkl	ijklnpw
Aspirin.....	gi	iklrsx	ijklnpqr
Baric.....	chijl	eijlrsx	ijklqrax
Barium Sulphate.....	agit	eiklrst	ijklnpqrxt
Barytes.....	abefgij	cefjlnoprs	ijlnpqrxt
Bauxite.....	abedeghijn	fgijlnopqrax	ijlnpqr
Bentonite.....	abefghij	fijkpqrs	ijknpqrwx
Beryllium Oxide.....	hi	ijkrs	jknr
Blanc Fixe.....	eghi	eijlst	ijlnqtp
Bleaching Compounds.....	hi	ijkrs	ijkrap
Bone.....	ceijl	eijlnrs	ijlnqrp
Boneblack.....	eghijl	eijklqrs	ijklnqrtpw
Borax.....	egi	eijlrs	ijlpqr
Boric Acid.....	egi	eijklrs	ijklpqr
Brick and Tile Grog.....	abedfgijopx	edfijnoprx	dijnpqr
Bronzes.....	a	n	n
Carbon, activated.....	efbi	eilorst	ijlmpqrstw
Carbon, gas.....	a	i	iw
Carbon, graphitic.....	abci	efiklnors	iklnpqrwtw
Carborundum.....	abdfj	fjknppr	knpqr
Calcite.....	abefgin	efilnprs	ilnpqr
Calcium Arsenate.....	abghi	fikrs	ijkapr
Calcium Carbide.....	abceij	cefijklnoqr	ijklpqr
Calcium Carbonate.....	abefij	eijklnor	ijklnpqrxt
Calcium Cyanamide.....	ghi	iknor	ijknpr
Calcium Hypochlorite.....	i	ikrs	ijkpr
Calcium Phosphate.....	ij	ijkpr	ijknpr
Castor Pomace.....	hi	irs	ijpra
Cement Clinker.....	abcefgjn	cefnprt	npqrvtx
Cement Rock.....	abedfijn	efijnprt	ilnpqrvt
Ceramic Mixtures.....	x	x	x
Chalk.....	abefghijls	efijklnoqrst	ijklnpqrstx
Charcoal.....	cefgbil	chijlqrst	hijlmpqrst
China Clay.....	efghijs	efghijklqrax	ijklnpqrswx
Chomite.....	ab	fnor	nqr
Clay.....	abefghijns	efghijklnoqrax	ijknpqrswx
Citric Acid.....	ch	eils	ilnqs

# MECHANICAL PROCESSING OF CHEMICAL MATERIALS

Material	Coarse (Down to 1/4 in.)	Intermediate (1/4 in. - 40 mesh)	Fine (Under 40 mesh)
Coal, Anthracite.....	abdefghij	defijnoprst	definpqrstx
Coal, Bituminous.....	abefghijnp	dfhijknoprst	dhiijknprstuvx
Coal, Lignite.....	abefghij	defijknopr	dijknpruv
Cobalt Oxide.....	i	ikr	ijknr
Coke, Bituminous.....	abefghij	edefijnoprst	deijnoprsvx
Coke Petroleum.....	abefghijo	sefijknopr	eiknopr
Copal Gum.....	fi	ijs	ijnpr
Copra Cake.....	ehil	ijls	ilnps
Cork.....	ehil	chijlqst	hijlpqst
Corundum.....	aj	fjn	n
Cottonseed Cake.....	hils	ehijls	hijlpqs
Copper.....	abe	fa	n
Copper Oxides.....	i	ikr	ijknprw
Copper Sulphate.....	i	eijklr	ijknprq
Cream of Tartar.....	i	ijkrs	ijkpqrs
Cryolite.....	ai	fi	ijnprq
Diapores.....	abi	ilr	jlqr
Diatomaceous Earth.....	abefghi	efgijklnqrs	gijklnpqrwx
Dolomite.....	abcdfijo	efijnopr	inpqrstx
Drugs.....	eil	eijklqrsx	ijklnpqrst
Dry Colors.....	hi	hijlrs	ijnprqrsx
Dyestuffs.....	chi	hijrs	ijnpraws
Effervescent Salts.....		x	
Emery.....	af	efnr	npr
Enamel Frit.....	aci	efnr	inpqr
Enamels.....	ai	fir	inprw
Feldspar.....	abefij	efijnopr	ijnprtx
Fertilizers.....	aeijl	fijlpr	inprv
Filter Cake.....	chis	chijlrat	hijlnpqrst
Fire Clay.....	abefgij	fgijnlpqrs	gijnlpqrs
Fish Scrap.....	il	cijs	ijnpsw
Flaxseed.....	il	ilqrs	ipqr
Flint.....	abef	efnopr	npr
Fluorspar.....	abefij	efijnopr	inpqrstx
Forsterite.....	i	lr	jpr
Fullers Earth.....	abefghij	fhiijknqr	ijnprqrs
Ganister.....	abedefj	efijnopr	npr
Garnet.....	abfj	efjnor	npr
Gelatin.....	hijl	hijl	ijnlpqx
Glu.....	hijl	cefhijkrlr	ijnprx
Grain.....	cijs	ijlqs	ijpqrs
Graphite.....	abefijo	efijklnort	ilnpqrstx
Greensand.....	abdel	defno	dnp
Gilsonite.....	abehis	fhins	ijnpr
Gypsum.....	abefgij	efijnoprst	ijnlpqrstx
Hematite.....	abfi	finop	ijnptx
Herbs.....	il	ijls	ijnlps
Ice.....	ei	in	i
Ilmenite.....	abi	finop	npt
Infusorial Earth.....	fghi	fij,qrs	ijnlpqrst
Ink.....	i	ij	ijnw
Insecticides.....	hil	hijls	ijnlpqswx
Intermediates.....	ac	eilp	ilnpq
Iodine.....	is	is	ijn
Iron Borings.....	ij	ijnpr	inpr
Iron Oxide.....	abij	fiknoprst	ilnpqrstwx
Iron Sulphate.....	gi	gikrs	ijpr
Iron Sulphide.....	agij	giknprs	ijnpr
Kaolin.....	abefghijo	fhiijlneqrs	ijnlpqrstwx
Kieselguhr.....	ghij	egijlqs	gijntx
Kelp.....	hil	hijlrs	hijnpwr
Kemite.....	i	i	j
Kryolith.....	ai	fin	ijnpr
Kyanite.....	abi	fino	ijnprx
Leather Scraps.....	ils	ijlrs	ilnpaw
Lime, chemical.....	abegijn	fijklnors	ijnlpqr
Lime, hydrated.....	abegijn	fijklnrat	ijknprst
Lime, quick.....	abgijn	fijknr	ijknpr
Limestone.....	abedfgijn	edfijklnoprst	dinpqrstvx
Litharge.....	agij	ijrs	inpqr
Lithopone.....	agij	efijnopr	ijnlpqrstw
Lithium Ores.....	i	efnr	ijnpr
Magnesia.....	abefgij	efgijlnrs	ijnlpqrsw
Magnesite.....	abg	fgilnpr	ijnlpqr
Magnesium.....	abi	filnr	ijnlpqr
Magnesium Carbonate.....	abgij	fgijnoprs	ijnpr
Malt.....	ijs	cijs	ijpq
Manganese Dioxide.....	abgi	fginoprst	gijnprst
Marl.....	abegij	ijnpr	ijnlpqr
Menthol.....	hi	hils	ij
Mica.....	hilo	ijnloqax	ijnlpqrstw

Material	Coarse (Down to 1/4 in.)	Intermediate (1/4 in. - 40 mesh)	Fine (Under 40 mesh)
Milk Sugar.....	abei	fij	ijnlpqx
Molybdenum Ores.....	abei	efnopr	npr
Monazite.....	ab	iora	ijnopr
Nepheline Syenite.....		n	n
Niter Cake.....	eghi	chikrs	hijkpr
Olivine.....	i	i	j
Oxalic Acid.....	i	irs	jpr
Oyster Shells.....	abefgijn	egijloprs	ijnlpqrsw
Paint.....	i	ijr	inprw
Paris Green.....	i	ijkpr	ijknpr
Patronite.....			n
Peanuts.....	il	iklqr	jkprw
Pebble Phosphate.....	abefgijm	cefiijnopr	ilnpqrw
Pigments.....	egi	ciijlr	ijnlpqrstwx
Pharmaceuticals.....	eil	ciijklrsx	ijknlpqrstwx
Phosphate Rock.....	abefgijm	cefiijnopr	inpruv
Pitchblende.....	ahi	hik	jkp
Plaster.....	egij	gijklrat	ijklnpqrstx
Plaster of Paris.....	egij	egijklrs	ijknpr
Plastics.....	chijl	cefiijklrsx	ijnlpqrsw
Plumbago.....	hi	efhrst	ijnprstx
Potash Ores.....	abefgijn	efginor	ijnopr
Potash Salts.....	afgi	gijlrs	ijpr
Potassium Chloride.....	afi	ijrs	ijr
Potassium Nitrate.....	afi	irs	jr
Pottery Glaze and Slip.....	aij	efijpr	ijnpr
Pumice.....	abefgij	cefiijklntpr	ijklnpqrstx
Pyrites.....	abedeij	defijnopr	dnopr
Pyrolusite.....	abi	finop	inop
Pyrophyllite.....		n	n
Pyrrhotite.....		defijnopr	dinopr
Quartz.....	abedefijn	fijlpr	ijnpr
Resins, natural.....	aghi	fhiijlrs	ijnlpqr
Resins, synthetic.....	aghi	edefhijklntpr	dijkpqrstx
Rock Salt.....	abedefghijt	chijlrs	ijnpr
Rosin.....	acgij	fgijklrs	ijklnpqr
Rubber, hard.....	hij	hij	ijnlpqrstwx
Rubber, soft.....	hil	hils	ijps
Rutile.....	abi	finor	inor
Sal Ammoniac.....	gi	ijr	jr
Sal Soda.....	ei	ciijklrs	ijkpr
Salt Cake.....	acij	ijklrs	jkpr
Sand.....	abedef	defiknors	dknopr
Shellac.....	egil	egijlr	ijnpr
Silica.....	abedef	aedeflnopr	dlnpr
Silica Gel.....	a	air	inpr
Silica Sand.....	abedefijn	aedefijnor	dlnpr
Silicon Carbide.....	abcj	afjnr	lnpr
Sillimanite.....	abc	ino	no
Soap.....	hi	hijls	ijnlpsw
Soda Ash.....	acfi	ciijklr	ijklnpqr
Soda, Bicarb.....	efi	ijklnqrs	ijkpqr
Sodium Nitrate.....	fi	ijkrs	ijkpr
Sodium Phosphate.....	acfi	ciijklr	ijkpqr
Sodium Silicate.....		n	n
Slag.....	abedefij	edefijnopr	dlnpr
Slate.....	abefij	efijnopr	inpr
Soybean Cake.....	chis	chijklrs	ijknlpqrsw
Sugar.....	i	ijkrs	ijkpqr
Sulphur.....	abefghij	cefiijknrs	ijknlpqrw
Superphosphate.....	ceij	cefiir	ilnpqr
Sylvanite.....	abeef	finp	inpr
Talc.....	abeghij	fhiijknprst	ijknlpqrstx
Tankage.....	hi	hijrs	ijrs
Tin Oxide.....	i	fiknr	jknpwr
Titanium Dioxide.....	i	finpr	ijnlpqrw
Titanium Pigments.....	abgi	cefiinor	ijnlpqrw
Triple Superphosphate.....	abceij	cefiinr	lnpr
Tripoli.....	abeeghi	efginoqs	ijnoprstx
Tungsten Ores.....	abedf	efnopr	inpr
White Lead.....	i	ir	ijnpr
Whiting.....	abei	efilnrst	ijnlpqrstwx
Wood Chips.....	il	ijls	inps
Wood Flour.....	ils	ils	inpsx
Wood Rock.....	ai	ijl	il
Zinc.....	abecj	fin	ijnpr
Zinc Oxide.....	i	ikpr	ijknprw
Zinc Sulphate.....	fijnr	ikr	ijknpr
Zincite.....	i	ip	ijp
Zirconia.....	i	i	j

# Size Distribution in Crushing

*CRUSHING HAS not received the same amount of fundamental study that has been given to finer disintegration operations. A recent investigation, however, affords interesting crushing data.*

EARLIER ARTICLES in this series have dealt with the fine and intermediate ranges of size-reduction. Crushing, a term generally used to describe the coarsest range, is sometimes considered to be divided into breaking and secondary crushing. Operations in this class are generally accomplished by pressure, although in certain types of equipment, impact alone or impact plus pressure is used, while in others, pressure is combined with a tearing action. The most common coarse crushing devices are the jaw, gyratory and swing-hammer crushers, while for secondary operations, cones, swing-hammer mills, rolls and rotary crushers are those chiefly employed. A number of modified forms of these types are also in use.

Jaw and gyratory crushers and sometimes swing-hammer mills are built in sizes large enough to handle run-of-mine materials, in capacities up to several hundred tons, or even more than 1,000 tons per hour. Cones are built with feed openings up to a foot and more. For the crushing of friable materials, single-roll crushers, which combine pressure, impact and shear in driving the material against a stationary breaker plate, permit relatively large feed sizes, in comparison with the double-roll crusher which seldom handles feed over 3 in., and is generally used for considerably smaller material.

Although the equipment for breaking and secondary crushing has been thoroughly and carefully worked out from a mechanical standpoint, while its field of use has been quite well standardized, there appears to have been much less study of coarse size-reduction than of the intermediate and, particularly, of fine reduction. There has, for instance, been little work on the shape and size distribution produced by coarse crushers. An exception to this statement occurs in the case of a series of recent investigations carried out by the U. S.

Bureau of Mines, dealing with the action of jaw, gyratory and single-roll crushers on a variety of rock. The results, reported in three progress reports, Report of Investigations Nos. 3377, 3380 and 3390, cannot be summarized here except to mention the findings with respect to the shape distribution under a particular set of circumstances. The results are indicative, but must not be assumed to hold rigorously in other circumstances.

Among other parts of the investigation, as reported in R.I. 3390, the Bureau studied the relation between the particle characteristics of the product and the ratio of reduction for a single pass of limestone through a 48 x 36-in. Blake crusher. Tests were made on 8½- to 24-in. lumps of two limestones, one uniform with few seams and little evidence of shattering, and the other shattered and filled with mud seams. The following conclusions were arrived at for both limestones and it is possible that they may also be characteristic of materials similar to limestone:

1. An increase in the ratio of reduction, i.e., particle size of feed divided by particle size of product, for a single pass through the crusher causes an increase in the amount of fines produced.

2. Of the various sizes of particles obtained in a single crusher product, those nearest the size of the crusher discharge opening will most closely approach a cubical shape. Furthermore, it was found that for a given crusher discharge opening, the "cubicity" of the discharged particles decreases in an approximate straight line ratio with the increase or decrease of their size from the size of the discharge opening.

3. An increase in the ratio of reduction for a single pass through the crusher gives an increased proportion of slab- and plate-like particles in the product and a corresponding decrease of cubical particles.

Additional crushing tests made by

the Bureau on a fine-grain gray biotite granite (R.I.3380), using both a Blake 60 x 48-in. crusher and a 27-in. shaft gyratory crusher, indicated that particle shape is a function of ratio of reduction rather than of the type or setting of the crusher, in so far as gyratory and Blake crushers are concerned, and that the smaller the ratio of reduction the more nearly cubical the product. This latter conclusion, it will be noted, was also found to hold true in the limestone tests.

## CLOSED-CIRCUIT GRINDING

(Continued from page 235)

in a reduction in plus 150-mesh material and also in the superfines, is shown in the table below. This size analysis was made by means of an Oden sedimentation balance, a device for making very accurate size determinations in the micron range. The open-circuit analysis is of a month's composite sample of cement slurry ground by the open-circuit method at a well-known cement mill. The closed-circuit sample was taken from closed-circuit grinding operations at the same mill.

Table II—Oden Size Analysis of Cement

Diameter, Microns	Equivalent Sieve Mesh	Open-Circuit % Cum.	Closed-Circuit % Cum.
295	48	0.32	....
208	65	0.68	....
147	100	2.18	0.08
104	150	4.10	0.38
74	200	7.85	3.75
53	325 dry	13.8	15.6
42	325 wet	15.9	19.15
40	...	19.3	23.3
30	...	23.5	31.0
25	...	27.6	34.7
20	...	33.1	39.4
15	...	39.9	44.9
10	...	48.5	51.7
7.5	...	53.4	57.0
6.0	...	57.6	60.5

**Savings**—At the cement plant from which the above data were obtained the following savings in grinding power and grinding media consumption were recorded:

Consumption Per Bbl.	Open-Circuit	Closed-Circuit	Saving %
Power, kw.-hr. ....	5.5	3.01	45.3
Primary media, lb. . .	0.086	0.057	33.7
Secondary media, lb. .	0.321	0.112	65.1

**Automatic Control**—A point worth noting is that in closed-circuit grinding, the classifier gives a control which automatically takes care of small fluctuations in character and rate of feed, which otherwise would cause variations in the finished product. Harder feed, for example, simply increases the circulating load.

MR. VALENTINE seeks to correct the condition which makes it necessary to limit mixing discussion to a brief 3 pages.

# Program for Mixing Study

BY KENNETH S. VALENTINE, *New York manager of Patterson Foundry & Machine Co., a chemical engineer who has devoted his professional life to the study and solution of mixing problems. Long a constructive critic of outmoded mixing ideas, Mr. Valentine was co-author of the mixing section in Perry's "Chemical Engineers' Handbook."*

IN ITS "Balance Sheet Issue" in 1934 *Chem. & Met.* carried an article by the author and Gordon MacLean (May, 1934, p. 237), which took into account the then status of the unit operation of mixing, and attempted to balance its "assets" against its "liabilities." It would seem that the time has come for another stock taking. What progress has been made in the intervening years? What "liabilities" still remain?

Some progress has been made in research. Hixson and Tenney (*Trans. A. I. Ch. E.*, Nov., 1934), and Hixson and Luedke (*Ind. Eng. Chem.*, 33, 1937), are undoubtedly working in the right direction in solving certain fundamental mixing problems. White and his co-workers at the University of North Carolina (*Ind. Eng. Chem.*, Oct., 1932, Sept., 1933, Jan., 1934; *Chem. & Met.*, p. 370, July, 1936; *Trans. A. I. Ch. E.*, May, 1935), made a study of the mixing of sand and water that is not without its special interest. MacMullin and Weber (*Trans. A. I. Ch. E.*, May, 1935; *Chem. & Met.*, p. 317, June, 1935) have made a most interesting and exhaustive study of great practical value on short circuiting in continuous mixing. This is useful in solving an increasing number of mixing problems where continuous flow is involved because the figures here presented enable one to calculate with great accuracy the number of stages and the capacity of each stage for a great variety of conditions. These authors also recognize the fact that the container is a true part of the mixer, bringing out the point that for best

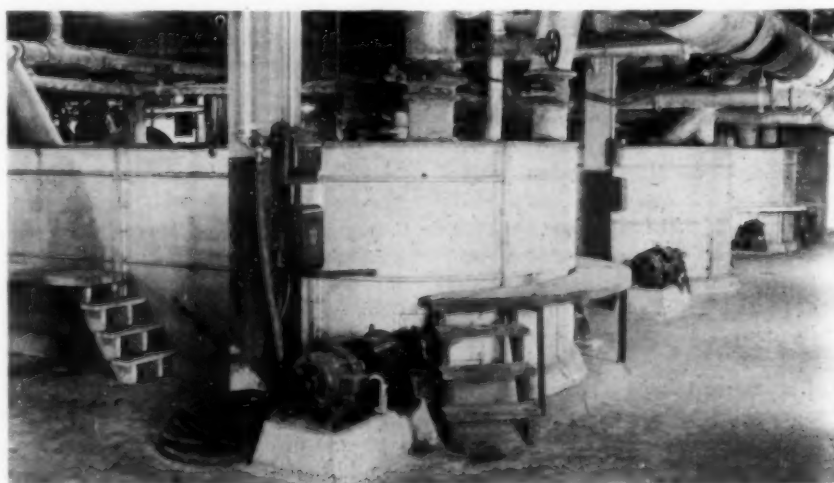
and quickest results the container itself should be streamlined.

There has also been a healthy tendency in some industries to eliminate too highly specialized mixers. In the May, 1934, "Balance Sheet," one of the liabilities listed was "Lack of standards. Use of different types of mixers in the same and in different industries for essentially the same problem." The elimination of peculiar devices was an object of a portion of the work of Valentine and MacLean in the mixing section of Perry's "Chemical Engineers' Handbook." (See "Fitting the Mixer to the Operation," *Chemical Engineers' Handbook* pp. 1295-1308). There is progress in this direction. For many years there have existed too many varieties of machines to do exactly the same class of work. For instance, some years ago five types of mixer,

namely, air, outside circulation (4)\*, paddles (9)\*, propellers (20, 21)\* and turbines (28)\*, were in use for mixing of thin liquids with liquids, or thin liquids with solids. The air and outside circulation types, although comparatively inefficient, were widely used in the petroleum, mining and heavy chemical industries. Recently there has been a marked decrease in the amount of mixing done by these methods and a large increase in the use of the much more effective propeller and turbine types for mixing in these industries, thus bringing them into line with other industries where propellers and turbines have been extensively used for many years.

Similarly, the paper beater (38)\*, a special type used in the paper industry, no longer has a clear field for certain classes of work. In many

Fig. 1—Noble & Wood propeller agitator applied to a cast iron stock chest in a paper mill; a similar agitator is installed out of sight on the far end



\*Numbers refer to particular mixing types so numbered in Perry's *Chemical Engineers' Handbook*, Section 14.

cases it is being superseded by the propeller type of mixer which is similar to Type 21\* in the respect that it enters the chest horizontally as in Fig. 1. A constriction in the flow passage forces all the pulp to flow through the propeller. Such a set-up gives better transportation and considerable hydration of stock, although it probably is not capable of producing as intensive an action as the beater when the beater knives are set up close. Nevertheless it illustrates the penetration of a more commonly used type into a field where a special type formerly dominated.

For the mixing of dry powders and granular materials, the double conical dry blender shown in Fig. 2 is gaining much ground. It might be termed a special type of the tumbling barrel (34)\*, although the conical style has the great advantage of much more rapid mixing owing to the fact that the material drops with considerable force from the upper to the lower cone as the mixer rotates. The falling material is deflected from the sides of the cone at a great variety of angles. Under these conditions a maximum of 200 revolutions is sufficient to give a perfect mixing of most dry materials. As all angles within this machine are obtuse, there are no sharp corners where material can collect. The conical shape makes discharging quick and thorough. This machine gains ground at the expense of the tumbling barrel and the ribbon mixer (25)\*. The tumbling barrel formerly had vogue in certain fields, such as dry color mixing; whereas the ribbon mixer has been more ex-

tensively used in the mixing of other products, such as starch and fertilizers. However, it appears that the double conical dry blender will continue to penetrate all the process industries. Once again special types are being eliminated by something which has a more general application.

As another instance it may be mentioned that whereas a great variety of types, such as vertical and horizontal paddle mixers (7, 8, 9)\*, dough mixers (17)\*, and propeller mixers (20, 22)\*, were formerly used to a large extent for the dissolving and mixing of viscous materials up to 350,000 centipoises, today the turbine types (27, 28)\* have replaced all of these almost completely throughout every industry where high viscosities obtain, as in rayon, photographic film, synthetic resins, and paint and lacquer. As in the cases already noted, a considerable cross-section of process industry has recognized the essential similarity of the requirements of a variety of differently named mixing problems and so has taken a step toward standardization on the most efficient mixing type for its needs.

Improvement of special types is also worthy of note. Pulp shredders (17-B)\* have recently been improved by the use of two double-sigma blades instead of two single-sigma blades. This change, though seemingly small, has made a great difference to the rayon industry in the speed and quality of the work done. The viscose rayon industry is also constantly benefiting by improvements in xanthate dissolving equipment, having turned to turbines. Several years ago

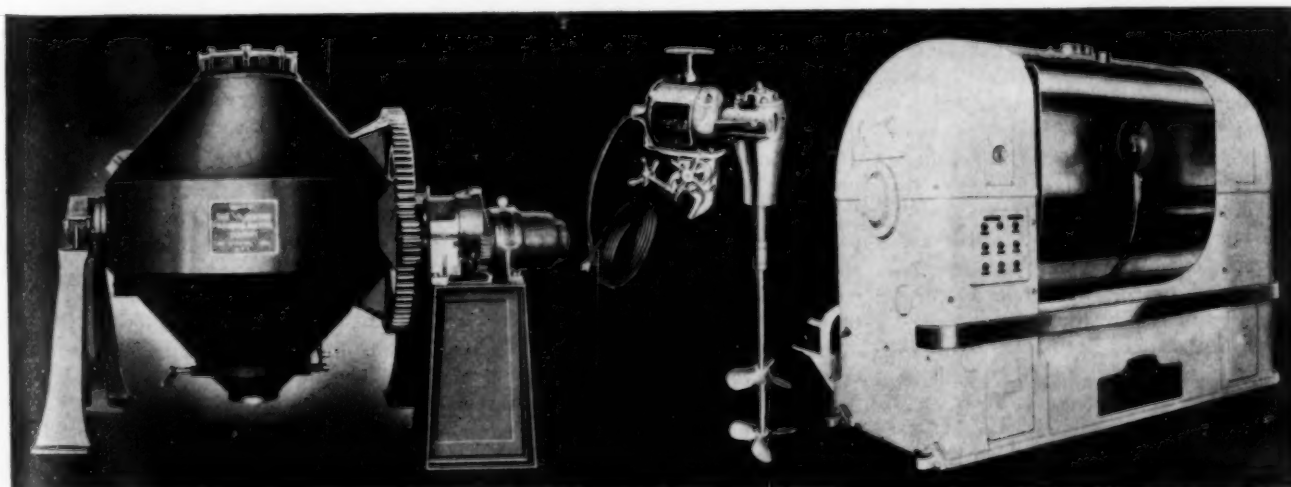
the best time for dissolution with standard turbine dissolvers was around  $3\frac{1}{2}$  hours, whereas today this is cut approximately in half. The saving in this case is important in promoting general plant efficiency and a faster operating cycle.

Banbury mixers, which may be described essentially as an extremely heavy variation of Type 17\*, have gained greatly in the rubber industry and are also being used in the making of molding compounds and lacquer. Because of the tremendous pressures which they exert (several tons per square inch), they have the ability to produce intimate mixtures of plastic materials and thorough dispersions which are attainable by no other commercial method.

In addition to improvement of types, some mixers have been improved from a mechanical standpoint. For instance, the geared type portable mixer, illustrated in Fig. 3, was introduced less than a year ago. It employs for the first time right angle gears and the motor set in a position at right angles to the vertical shaft. This saves headroom and permits the vertical shaft to be shortened or extended over a great length.

Generally speaking, the most common mechanical improvement of the last four years is the present widespread use of motor-reducer units. For instance, Figs. 1, 2 and 3 show such units. In the case of large stationary vertical mixers, it is probably true that more than 50 per cent of all the installations being made today are driven with a vertical motor-reducer unit connected directly to the

Figs. 2, 3 and 4—Left to Right—Patterson conical blender for dry powders; Patterson right-angle-geared portable mixer with variable shaft length; Read Machinery streamlined dough mixer of a type now penetrating the food industry



vertical shaft. At least 80 per cent of the remainder are driven by horizontal motor-reducer units connected through worm or bevel gears to the vertical shaft. This extensive change is actual, hard as it may be to believe that it could have taken place within the last four or five years.

The practice of streamlining the outside of mixers has already gained great favor, especially in the food industries. Fig. 4 shows a dough mixer with all working parts concealed and with no sharp corners or ledges where dust or dirt can collect. A beautifully enameled finish makes such a machine as modern as a streamlined train.

What are the remaining liabilities? After a review of all personal experience and contacts over a wide territory, and careful consideration of much published material, an unavoidable conclusion has been reached that, in spite of the progress and improvements noted, there have been no startling developments of any sort in the mixing field in the past four years. There has been no brand-new type of mixer evolved. There has been no law formulated which would help solve either general or special mixing problems. There has been no directed effort toward a standardization of nomenclature pertaining to mixing in the process industries.

#### Guideposts for Improvement

Mixing is a unit operation which is probably used more nearly universally than any other, and yet it is doubtless the least scientifically developed of any. It still remains too much an art and not enough a science, and a great deal of work is needed to correct these conditions. Real progress, it is believed, would come from considered effort expended along three lines: (1) planned research to discover the laws of mixing; (2) intensive effort aimed at the development of a few mixer types suitable for the majority of requirements; (3) standardization in the methods of measuring and describing the variables affecting mixing.

There is surprisingly little literature on mixing research because no formulas exist. No mixing problem has yet been worked out mathematically from a given set of conditions. Yet it is felt that a blanket formula, including every variable, can ultimately be evolved. However, before this ultimate goal is reached, many problems leading to it will first have to be met and mastered. For

example, the following studies must be made, among others:

- (a) Relative value of various mixing elements at all viscosities, plasticities, or consistencies. For example, a comparative study should be made of paddle, propeller, turbine, and other types for liquid mixing.
- (b) Best design of any specific mixing element.
- (c) Influence of size of mixing element on efficiency of mixing within any given system or container.
- (d) Best points of application of mixing element or elements in any given system or container.
- (e) Relation of power requirement to general design of mixing element.
- (f) Relation of power requirement to peripheral speed of any given mixing element.
- (g) Relation of power requirement to consistency of material to be mixed.
- (h) Best shape of container to use in conjunction with any mixing element on any given material.
- (i) Distance any particle will travel in a given system after leaving the mixing element.

These investigations will have to be more or less empirical, but by observing and correlating results on the points given, and many others, a law can be evolved which will partially, if not wholly, evaluate mixing. No doubt the universities are best equipped to carry out this research. They are best able to develop engineering formulas based on mathematics. Besides they can take the detached viewpoint necessary in arriving at impartial conclusions where many manufactured types exist.

However, the practical side of such work should always be given serious consideration before a piece of engineering research is begun. For instance, to date there has been more research on paddle agitation than any other type. It would seem that such research is not of the highest practical value as long as types other than paddles exist, which are far more efficient. Therefore, the first step (a above) should be the endeavor to ascertain the best type for the purpose in view and then concentrate on this type in working out the balance of the problem in hand. Then, too, in future research it will probably be more valuable to compare peripheral speeds than to compare r.p.m., as the latter does not sufficiently take diameters into account. This difference in the way of thinking about the problem, although apparently unimportant, has often led to impractical results.

Again, it is to be hoped that the idea that power input is a measure of mixing in any given system, will be forever abandoned, for it is one

of the most egregious errors that still lingers in the minds of some of our first-rate chemical engineers. The following examples will show the absurdity of this idea:

Consider a tank 10 ft in diameter and 10 ft. high, at the bottom center of which is installed a 12-in. turbine mixer running at a peripheral speed of 700 ft. a minute (225 r.p.m.), having at this speed a pumping or circulating capacity of 1,100 gal. per minute and under these conditions requiring 0.35 hp. It can be proven that when turbines are used, pumping, or circulating, capacity is a fair measure of the average mixing being obtained within a container or system. When the speed of this turbine is doubled to 1,400 ft. a minute (450 r.p.m.), the pumping capacity is approximately doubled to 2,200 gal. per minute, but the power is increased more than 8 times, i.e., to 2.9 hp. Or, if this proof is not sufficient, suppose a 24-in. turbine is taken, running at 700 ft. a minute (112 r.p.m.), having the same pumping capacity as the 12-in. turbine at 1,400 ft. a minute, i.e., 2,200 gal. per minute. Whereas the 12-in. turbine requires 2.9 hp., the 24-in. turbine requires 0.65 hp., or only 22 per cent as much power to produce equal mixing results. (In actual practice the results will be a great deal better in many cases.)

#### Standardization Needs

It is not beyond the realm of possibility that a new mixer could be invented which would be so efficient on all types of liquid mixing that it would entirely supersede all of the types now used in various portions of this field. As has been noted earlier in this article, progress has been made in this direction, though no major step has yet been taken. It is further to be hoped that another mixer will be developed which will handle all plastic masses, doughs, and pastes. As for dry powders, the double conical blender is a partial answer to the universal mixer for this class of materials, although probably not the ultimate one.

Standardization of methods of measuring viscosity, plasticity, consistency, etc., and standard nomenclature on these subjects, are of an importance which can scarcely be overestimated. The author and Gordon MacLean have been advocating it for years. It seems that advocating is not enough; something must be done about it. Until the entire field is educated to use the same terms in discussing their problems, there are bound to be a great many applications of mixers to jobs for which they are not suited. It is impossible to solve a mixing problem correctly on the basis of inquiries received for "stirring a material about as heavy" (Please turn to page 285)

THE ARTICLE below introduces a section of 38 pages dealing with the broad range of process industry separations

# Particle Measurement Problems

BY LINCOLN T. WORK, assistant professor of chemical engineering, Columbia University, New York, who has worked on many phases of the particle size problem, in cement, pigments and other fields. Dr. Work is chairman of A.S.T.M. Technical Committee III of Committee E-1 on Standards for Particle Size and Shape.

ASSOCIATED with such operations as size-reduction, precipitation, mixing and filtration, is the problem of particle size measurement. There are many reasons why fineness is of interest in such operations as these, and in the products resulting from some of them. The effect of surface upon reaction rate is one of the most important. There are also specific considerations, such as the ease of filtering with different sized particles, the uniformity of a mixture as a function of particle size, and grittiness or abrasiveness as a function of such sizes. In the keen competition to speed up reactions and to improve the qualities of products, there has developed a marked interest in particle size, particularly in the finer sizes below the range ordinarily covered by sieves, i.e., less than 50 or 100 microns (thousandths millimeters).

A number of methods have been developed for measuring particle size characteristics of materials, and there has been a decided tendency for special methods to be developed for specific groups of materials. This has been done in the interest of expeditious testing and of current availability of testing equipment, and has often been quite independent of similar kinds of tests in related fields. Thus there are at the present time specifications for sieves with wire cloth having substantially square apertures, while in related fields perforated plate with round openings is specified for sieves. There are methods of settling particles and determining the distribution of their sizes which depend upon hydrometer measurements, upon

weighing the material as it settles in a cup, and upon measuring the opacity of the suspension during the period of sedimentation. Actually the number of principles involved in size measurement is comparatively small, but the diversity created by the many specific methods yields what is really a large group of tests for particle size.

A number of factors must be considered in the selection of a method for the measurement of particle size, among which are the particle diameters under consideration and the specific properties of interest in the product. In some cases the maximum size of particles may be of major interest, and a sieve test may be adequate, although a large portion of the material is finer than sieve mesh. In other cases, instead of such a bounding dimension, the surface of the material or the size distribution may be the important factor. The accompanying table indicates the range of size in which the different methods are most frequently employed. Each of these methods is discussed separately with particular emphasis upon the present problems and limitations associated with the method.

Size Ranges of Particle-Size Methods

Method	Microns
Sieve .....	50 to 100,000*
Microscope	
Visible spectrum ....	0.3 to 100**
Ultra-violet light.....	0.05 to 2
Settling velocity	
Elutriation .....	5 to 100
Sedimentation .....	1 to 100
Ultra-centrifuge .....	below 1
Turbidimeter .....	0.2*** to 50
Sorption .....	under 10

\* Upper limit of standard sieves.

\*\* Practical upper limit.

\*\*\* Lower limit when used without settling.

**Sieve Method**—Separation of materials into graded fractions from approximately 50 microns in size and coarser may be accomplished by the use of sieves. The usual form of sieves comprises wire mesh or perforated plate mounted in a standard frame so constructed that a series of sieves may be nested together. The W. S. Tyler Co., of Cleveland, offers a standard series, while the U. S. Bureau of Standards has developed another but somewhat similar series. The latter is the basis for the present standard of the American Society for Testing Materials (E-11-26, A.S.T.M. Standards, 1936, p. 1413). With the exception of only a few sieves of 1-in. opening and larger, these standards are substantially similar. At the present time there is a committee of the American Standards Association at work upon a single standard into which both these series will fit within the allowable tolerance except for the specific exceptions noted above.

The sizes of apertures in a nest of sieves are usually arranged geometrically, so that they increase from finer to coarser sieves in steps proportionate to the square root of 2 or to the 4th root of 2—that is, about 40 per cent or 20 per cent increase, respectively, in lineal dimension of the aperture from sieve to sieve.

In the process of testing, an appropriate weight of material is placed upon the top sieve of the nest, and the nest is agitated until the rate of passage of material through each sieve is comparatively slow. The weights retained on sieves are recorded and computed to percentage. In some cases where material tends

to agglomerate and is not readily broken down into individual particles under the action of sieving, it is dispersed in a suitable fluid, washed through a sieve or series of sieves, dried and recovered for weighing. Wet sieving is also used to eliminate the fine particles which will pass the finest sieve of a nest, and the oversize material is then subjected to dry sieving procedure.

There are several unsolved problems associated with the sieving method at the present time. One of these is the uniformity of sieve cloth, which is particularly important in handling uniform materials, such as abrasives which invariably have a large number of particles which just fail to pass the average apertures but can pass the largest apertures in a given sieve. Uniformity of cloth is also important in the close nesting of sieves, particularly when dealing with the 4th root of 2 series. There is thus a problem in improvement in the uniformity of sieve cloth, and when it is considered that sieves become less uniform with use the problem becomes still more acute. There is some tendency to solve this by the use of perforated plates of finer sizes than have heretofore been used.

At the present there is considerable room for improvement in agitating procedures and also in agitating machines. Owing to the wide differences between materials no general answer appears practical, and each type of problem must be solved with respect to its own peculiar limitations.

A great deal can be done to lend accuracy to the sieve method by calibration of sieves under actual test conditions. This may be accomplished by smoothing the curve of log per cent on sieve versus log diameter and noting the departure of individual values from a smooth curve. Another method involves counting and weighing particles in a sieve fraction to yield the average size for the fraction. A modification of this consists in measurement of the size of particles which last passed through a sieve at the time a weighing is to be made. These methods take into account the structure and condition of the sieves as well as the method of agitation.

**Elutriation Method**—The variation of settling velocity of particles in a fluid with particle diameter is another basis of separation which is used extensively in the range of 5 to 100

microns. The fluid may be either a liquid or a gas, usually water or air. The devices are vertical tubes, one or several in series, so operated that the fluid rises at a controlled velocity to carry the fine particles out of the chamber and to leave behind those particles which settle more rapidly than the upward velocity of the fluid. In liquid elutriation the material is suspended in a fluid with suitable dispersing agents, subjected to the separation, and the individual fractions recovered by filtration through porous crucibles. They may be dried and weighed and the particles recovered for further measurements if desired. In air elutriation the dispersion is effected by the velocity of the air playing on the mass of material, and such velocity should not be so high as to abrade a given material, nor should it be so low that clusters of particles fail to be dispersed. The Pearson air analyzer (Pearson and Sligh, U. S. Bur. Stds. T. P. No. 48, 1915) is a single stage apparatus of this type in which sized fractions may be obtained by changes in air velocity. The Roller air analyzer (P. S. Roller, U. S. Bur. Mines T. P. No. 490, 1931) utilizes a series of chambers of different diameters for the fractionation. Since otherwise particles might adhere to the walls, a scheme of vibrating the chambers is utilized. The fine material may be collected in a dust filter, while the coarse material may be recovered at the bottom of each stage of the elutriator. Diameters are usually expressed as Stokes Law diameters, that is, as the diameters of spheres of the same kind of material which settle in the fluid at the same velocities as are used in the device. This diameter is different from that used in the sieve method, and if the elutriation is checked by microscopic observation there is a still different criterion of diameter.

Both liquid and gas elutriation procedures have been improved, and time consumed in making tests has been greatly reduced. There are, however, operating difficulties which make it desirable to check the method against inadequate separations and against abrasion of material by suitable control methods.

**Sedimentation Method**—The same principle of settling as used in the elutriators may be used without actually separating the material. If a suspension of particles in a liquid is shaken up until it is uniform and the individual particles are sufficiently

free to settle in accordance with Stokes Law, the changes in density or opacity or the weight of material passing a given plane in the chamber may be used to determine the distribution of particle size. The Microneter (R. T. Knapp, *Ind. Eng. Chem. Anal. Ed.*, 6, 1934, p. 66), the Buoyoucos hydrometer (Biddle and Klein, A.S.T.M. Proc., 36, 1936, p. 310), the Wagner turbidimeter (C-115-34T, A.S.T.M. Proc. 35 I, 1935, p. 777; also A.S.T.M. 1935 Tentative Stds., p. 432), and the Oden balance (S. Oden, in Alexander's "Colloid Chemistry," Vol. I, p. 861), have all been extensively developed for this purpose. Each of these has specific problems of technique and calibration, and one of their limiting features lies in the fact that dilution of particles insures freedom of settling, while dilution at the same time lowers the sensitivity of the observation which is to be made.

**Microscopic Method**—For the finest ranges of sizes—that is 0.3 to 8 or 10 microns—and to a certain extent all the way up to the finer sieve sizes, the microscope has found a place as a means of measurement of particle size distribution. The method consists essentially in making a properly dispersed slide, in which the several sizes of particles are uniformly distributed, and counting the frequency of occurrence of particles in each of several size ranges. Frequency values may be utilized directly, or they may be computed to a weight basis. For ease and simplicity in making such a count, photographic or projection methods are commonly used.

If the size distribution of the particles varies over a wide range, the problem of sampling becomes an acute one, and the number of particles to be counted becomes increasingly important. In one curve appearing in the literature 200 particles were counted, and one particle of the 200 was about 50 microns in size. The remainder were largely under 10 microns. When computed to a weight basis that one particle represented 50 per cent of the weight of the sample. There are several ways to secure a correct distribution without an unduly large count. Weigel (U. S. Bur. Mines T. P. No. 296, 1924) has shown how to make correction counts based on field areas, and the author has proposed correction counts based upon a proportion of distribution in the various size ranges. By so doing, a count of a

few hundred or a few thousand particles may suffice to measure a wide distribution as to size and yield quite accurate results. The method is likely to be tedious and difficult, but with experience it can be simplified considerably.

Due to the optical fringes which appear on the particle images, it is dangerous to rely upon microscopic measurement in the range of 0.2 or 0.3 microns. However, the use of ultra-violet light permits microscopic measurement to still lower sizes with reasonable accuracy.

**Turbidimeter Method**—A suspension containing a given amount of solid will obscure light in terms of fineness of that solid. With many materials this is a good indication of surface, as the projected area of the particles is directly measured by obscuring power. The author has used the Jackson turbidimeter since 1921 in making relative turbidimeter measurements. Stutz and Pfund (*J. Ind. Eng. Chem.*, 19, 1927, p. 51) have used a turbidimeter for pigment par-

ticles and have found a difference with red and green light due to the fact that certain of these fine particles permit red light to pass around them while green light is still absorbed. The author has found that the use of red and green light with the Jackson turbidimeter yields two values of turbidity, and the difference between these becomes a colloidal index measuring roughly the amount of particles between about 0.25 and 0.35 microns. The Wagner turbidimeter (*op. cit.*) has been devised for measuring sedimentation by means of light passing through a suspension on to a photoelectric cell, but it may also be used to determine the turbidity of a suspension directly and without sedimentation.

The range of particle size covered by the turbidimeter is from about 0.2 to about 50 microns, but its greatest value lies from about 0.4 to 5 microns where the obscuring power of the particles is great compared to that above or below these values.

Above these values the surface of the particles diminishes rapidly with size, and below these values the particles become less than half the wave length of light and fail to obscure the light.

**Miscellaneous Methods**—A number of special methods have been developed. Chief among these are the sorption of dye or vapors upon solid surfaces, the rate of dissolution of fine particles in a solvent, and the dispersion of the X-ray diffraction pattern. The sorption of vapors under controlled humidity conditions offers possibilities of measuring surface but is subject to selective differences. For example, the author has used equilibrium moisture and a corresponding test with carbon tetrachloride on coals and has found that the sorption values are not in the same relation when water is used as they are when carbon tetrachloride is used. There are still a number of unsolved problems with respect to this method and its corollary, the absorption of dyes.

## Trends in Screen Separation

*ONE OF the most used methods of separation, screening is probably the best understood. Nevertheless, constant development has taken place and many new mechanisms have appeared.*

FOR THE SEPARATION of particles on the basis of size in ranges from coarse to and including the intermediate, screening is the method that has been most employed. Its equipment is of comparatively simple construction and low cost, its results can be controlled with a considerable degree of accuracy, and its operating costs are relatively low. Screening media are constantly being made more accurate and more durable, but the most striking development in recent years has been in the mechanisms that have been developed for agitating the screening surface. A few years ago it became evident that designers were working toward simple mechanisms to impart uniform vibration to the entire screening surface. Some recent designs are arranged so that agitation of the screen

surface produces the desired forward conveying even with a level deck.

Any attempt at classification of screening mechanisms can probably be criticised on a variety of bases, but the attempt will nevertheless be made here. For coarsest screening, grizzlies are used and these are generally of the plain bar type set at a slope greater than the angle of repose of the material; or of the reciprocating bar type capable of conveying the material; or of the roller type. Very coarse materials, such as mine-run rock and coke direct from the oven are so handled. In the next size range, both rotating cylindrical screens, or trommels, and shaking and vibrating screens are used. The recent development, however, has taken place in connection with the latter types, and they alone will be considered here. Such screens range in purpose from rela-

tively coarse to relatively fine separations.

Producing motion of the screen surface in a stationary screen is accomplished in a great variety of ways, all of which, however, fall into a relatively few fundamental types. Among shaking screens, the type reciprocated by an eccentric, and various varieties of gyrating screen may be distinguished. A recent tendency in the latter type has been to produce truly circular motion of the entire screen surface.

In vibrating screens, until recently the principal types were those employing mechanical tappers for the screen surface, and those with the surface rapidly vibrated by an alternating current magnet. With the development of the vibrating electric conveyor, however, the same principle has been applied to screens, with the result that vibration of the entire surface is produced in a forward direction, so that conveying is accomplished on a screen that may be level or even slightly sloping upward toward the discharge.

Among mechanically vibrated screens, a few years ago there was a rapid introduction of two new types in both of which the entire screen deck is vibrated. One type makes use of a rapidly rotating unbalanced weight journalled on a

(Please turn to page 252)

# Character of Woven Filter Media

*BY R. O. PRIOR and R. GORDON WALKER, respectively, vice-president of Filter Media Corp., Irvington-on-Hudson, N. Y.; and vice-president of Oliver United Filters, New York. Mr. Prior's business life has been given over to filter cloth development and manufacture. Mr. Walker's long association with all phases of filter development in the process industries is too well known to need reiteration.*

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FOR MANY YEARS the fabrics which were employed as filter media in industrial filtration were confined solely to mechanical fabrics whose original designs were created for entirely unrelated purposes. Consequently the performance of these fabrics as filter media in many cases left much to be desired. More recently, however, through the design of specific fabrics for industrial filtration, the efficiency of clarification and filtering capacity have been greatly improved.

Woven filter media now comprise a large number of styles woven from a multiplicity of organic and inorganic materials. Cotton, wool, hair (both animal and human), metal, asbestos and glass are the principal materials from which these media are fabricated.

Of these numerous materials the use of cotton is the most widespread for several well founded reasons. It is mechanically strong and is the most economical in initial cost of any suitable textile fiber. A further and very important feature of cotton as a raw material for filter cloth is the basic structure of the yarn which it forms. From the surface of cotton yarn a great many hair-like filaments project and these are of great assistance in preventing bleeding at the start of the filtration cycle. They tend to catch and hold the initial solids that are forced against the surface of the filter medium and sustain them there, after which the cake formation itself becomes the filter medium and the cloth simply sustains the cake.

This inherent characteristic of cotton permits the use of more porous weaves to obtain the same clarification efficiency than it is possible to obtain with comparably porous fabrics having fibers of greater smoothness. The result is an increased filtering rate without sacrifice of clarity.

Application of cotton filter cloth is limited by the chemical characteristics and temperature of the solutions to be filtered. Solutions having either a very low or high pH are corrosive to cotton and this corrosion is progressive as filtering temperatures increase, even where the pH values more nearly approach the neutral. Also high temperatures alone can limit the application of cotton as a filter medium. This is illustrated in the filtration of lubricating oil mixed with contact clay. In many instances the temperature at which this filtration is conducted causes the rapid breakdown of cotton cloth even where the solution itself is neutral.

The corrosive effect of caustic solutions on cotton filter media can in numerous instances be economically offset through the impregnation of the cloth with a combination of rare earth salts, with a resultant increase in cloth life sufficient to justify the cost of such impregnation. Also, other treatments are available to retard the growth of bacterial and fungoid organisms where operating conditions are such as to foster their growth on cotton cloths during their period of service.

Wool is the next most important textile fiber in point of use in the

manufacture of filter cloth. While wool fabrics are about five times greater in initial cost they have certain characteristics not found in cotton filter media which justify their use in numerous instances. Like cotton the fiber of wool makes it an excellent raw material for filter cloth as it produces a hairy yarn and has excellent mechanical strength. Wool, being an animal fiber, is more acid resistant than cotton and will also withstand considerably higher temperatures without structural breakdown. These factors enable wool filter media to operate effectively where either acidity or high temperature or a combination of both conditions create such a rapid breakdown of the structure of cotton that it becomes uneconomical to employ it even in the face of its much lower initial cost.

Filter media fabricated of human hair, camels hair, mohair and similar fibers, as well as various mixtures of them, are particularly well suited for use in connection with hydraulic presses. Such fabrics are inherently high in tensile strength, a necessary feature to withstand effectively the high operating pressures employed. A further extremely important quality of woven hair media for hydraulic pressing is their elasticity which permits the cloth to be squeezed and distorted under pressure without cracking or bursting.

These fibers are similar to wool in so far as their acid and temperature characteristics are concerned. They do not, however, afford as effective filtering characteristics and as a con-

sequence denser weaves are required to obtain an equal degree of clarification efficiency. This results in lower filter output except in those instances where the cake formation is of equal or greater density than the medium.

In the fabrication of woven metal filter cloth, those metals most frequently employed are Monel, stainless steel, bronze and copper. The corrosion-resisting characteristics of the various metals make them suitable media for the filtration of caustic and acid solutions in concentrations that would be impractical to handle through media of either vegetable or animal fibers. Woven metal cloth in open weaves is unusually well suited for the filtration of fibrous stocks such as paper pulp and in this industry we find its most wide-spread application. The initial cost of woven metal filter cloth, particularly in the more closely woven styles, is a limiting factor in its use. Application must be confined to uses where long life can be obtained. This necessitates operating conditions where the

medium will not be rapidly broken down mechanically as well as where the solids to be filtered will not blind the cloth quickly or where it can be readily treated to remove the solids causing the blinding. Under such operating conditions excellent life can be obtained because metal filter media are strong mechanically and afford effective corrosion resistance.

Asbestos is another fiber which has special application as a raw material in the manufacture of woven filter cloth. The main characteristics of this fiber are its ability to withstand extremely high temperatures and a good degree of chemical inertness. One of the main detriments to asbestos filter cloth is the fact that asbestos fiber does not lend itself to being spun into a yarn of high tensile strength. The result is that, when woven, the cloth lacks the mechanical strength of other materials. The blending of cotton with asbestos is employed to improve this weakness but when such cloth is subjected to the high temperatures and corrosive conditions for which asbestos filter media are suited, the tensile strength of the cotton is soon destroyed and the fabric thereby appreciably weakened. In view of these facts the temperature and corrosion resistant advantages of asbestos fiber are limited by their comparative lack of mechanical strength and application must be confined to those filtrations where operating pressures are low and mechanical stress slight.

The most recent development in the field of woven filter media is the weaving of glass fibers into fabric form. The fiber employed is produced from a chemical glass and as a consequence affords a raw material which is highly resistant to most acids even in concentrated form. High operating temperatures can also be encountered without detriment to the fibers. In general, glass fiber presents one of the most stable and inert forms of raw material available at the present time for woven filter media. In addition it has been found that woven glass cloth is capable of sustaining unusually high flow rates in fabrics of a comparable density to other woven media.

Manufacture of woven glass cloth is too new to attempt to set forth the extent of its possible applications and limitations. From the extremely suitable filtration characteristics of the fiber itself the possibilities of its application as a filter medium are obviously wide-spread in chemical fields.

At present these advantages appear to be limited somewhat by reason of the mechanical limitations of the woven cloth. While these media have very high tensile strengths and are almost as pliant as fabrics woven from cotton or wool, they do not have the resistance of these latter to abrasion or continued flexing. As a consequence woven glass cloth cannot at present withstand as severe mechanical operating conditions as cotton or wool media.

It is possible to visualize improvements in the manufacture of glass cloth and in filter adaptation which will to some degree at least overcome the mechanical problems involved and thus enable fuller advantage to be taken of this new fiber's excellent filtration characteristics.

The foregoing paragraphs have set forth the main advantages and limitations of the most commonly used raw materials from which woven filter media are produced and the next point of consideration is the fabrication of them into filter cloth.

The filtration characteristics of woven filter media are controlled in three ways, namely by weight, thread count and weave.

Both the weight of the cloth as well as the number of ends or strands per inch contribute to the porosity and strength of the fabrics. From a theoretical standpoint a practically unlimited range of fabrics can be produced through different combinations of these two factors.

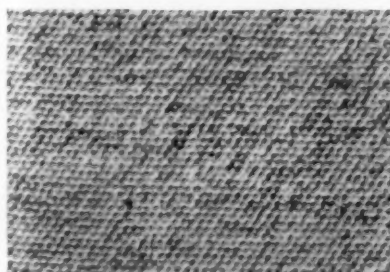
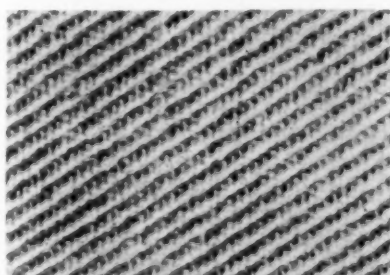
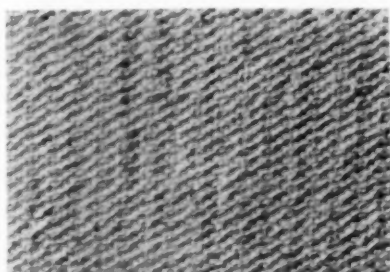
Porous heavy-weight fabrics can be obtained by using strands of large diameter with a small number of them per inch. Conversely, light-weight fabrics of low porosity can be produced by employing a very large number of strands per inch, each individual strand being of small diameter. By modifying the strand diameters and numbers of them per inch many variations between these extremes can be obtained.

In practice the different physical characteristics of the various raw materials used in the weaving of filter cloth limit the constructions that can be produced as compared to the theoretical extremes cited above.

The three principal weaves employed in the manufacture of filter cloth are the twill, the chain and the plain which are illustrated in the accompanying views. These three types of weave develop different degrees of porosity and flow capacity. When employing a construction of an equal number of strands of equal diameter,

Typical cotton filter cloths showing, at the top, a chain weave, and below it a twill and a plain weave

(Slightly larger than natural size)



a fabric woven in a plain weave attains the minimum degree of porosity and flow capacity. The twill weave is the next lowest in these two characteristics, while the chain weave affords the highest relative porosity and capacity.

In practice the choice of weave in the heavy and more closely woven constructions is at times limited by the physical characteristics of the various raw materials, particularly in so far as their tensile strength and resiliency are concerned. This is due to the fact that in the weaving operation the plain weave requires the greatest amount of mechanical force to obtain the given construction, the twill requiring somewhat less and the chain the least of all.

It is obvious that the selection of the weave of a filter medium is directly related to the filtration conditions which it must meet. Bearing in mind the characteristics of the three weaves in their porosity and flow-rate relations, this choice is correlated to the paragraphs which follow.

There is, however, one generalization in regard to weaves which can be made. Owing to the low flow capacity of the plain weave in the more tightly woven constructions, the use of this weave in these constructions is not well suited to vacuum or low-pressure filtration. As a consequence its use today is generally limited to plate type filter presses where high pressures can be employed and where the cloth can be readily replaced, since the plain weave is the one most subject to blinding.

Successful selection of a filter medium for a given problem must take into consideration the specific conditions surrounding it. Owing to the number of variables present in the manufacture of even the same finished products it is infeasible to attempt to generalize as to what style of filter cloth should be used for a particular class of products. In some instances such generalizations might be correct but there would be an equal number of cases where to follow such generalizations would result in failure or only partially satisfactory results. Experience has conclusively shown that individual operating conditions are the sole determining factor in filter media selection.

The first factors of consideration are the chemical and temperature characteristics of the solution to be filtered. The choice of the type of medium should be toward that whose raw material is least affected by the

chemical conditions to be present.

Next among the factors is the type of filter equipment to be employed. This may lead to a modification of the choice indicated by the first factors for several reasons. The type of filter might create mechanical conditions too severe for the raw material that is chemically best suited. Because of this another type of medium less chemically resistant but more mechanically adaptable would afford the most economical results. Likewise on certain types of filters the frequent changing of the filter cloth may present very little difficulty with the consequence that a less chemically resistant but initially lower priced material would serve more economically. This can be an important factor of consideration, particularly in those cases where the chemical conditions are not of sufficient severity to create too wide a differential between the life of two different types of media. Conversely the selection of the higher priced medium may well prove the more economical where replacement of filter cloth is both laborious and costly.

Further important factors of consideration are the physical characteristics of the solids present in the liquid to be filtered; and which part of the suspension, the solids or the liquids, or both, are valuable. The theoretical ideal is a medium so constructed that it will perfectly sustain the solids and still permit a more rapid passage of the liquid through it than is afforded by the cake that is formed. Such a construction will yield the highest filter output and, where the solids form a free granular cake, this ideal can usually be obtained.

There are, however, numerous solids, the physical nature of which precludes this and in these cases modifications must be made. Some solids are of such structure that they will rapidly blind those media of sufficiently low porosity to sustain them completely.

In such instances the approach is first dictated by whether the solids, the liquid, or both, are the valuable products. If it is the solids, and the liquid is waste, the most economical filtration procedure is to employ a filter medium of sufficient porosity to allow the passage through it of some of the finest particle sizes in order to prevent blinding of the medium too rapidly.

Where the liquid is the valuable product and the solids are waste, the

best results can usually be obtained by using a fairly porous filter medium in conjunction with a filter aid of diatomaceous earth or similar material. The filter aid can be mixed with the solution to be filtered, or a separate run of the filter aid can be employed to precoat the filter medium prior to the filtration cycle.

In the first instance a cloth of lower porosity is required than in the case of precoating. The choice between the two methods is mainly dictated by the type of solids that is to be retained. Where the more slimy and colloidal solids are present the precoating method is the more efficacious, both in preventing blinding of the filter medium and in obtaining the highest rate of filter output.

Where both the solids and the liquid are valuable, filter aids can also be employed but such procedure is limited to those cases where small percentages of them will not create an unsatisfactory impurity in the finished product. Where such impurity is not permissible and filtration must be used as the clarification method, the only solution is the employment of a filter medium that will afford the complete separation of the solids and liquid. Blinding of the filter medium with comparative rapidity cannot be avoided and equipment affording the easiest means of filter medium replacement should be employed.

#### SCREEN SEPARATION

(Continued from page 249)

structure attached to the deck, while the other supports a part of the weight of the deck on a rotating eccentric. Both of the types require considerable headroom, however, owing to the necessary deck slope. This limitation led to the development of several mechanical counterparts of the electric conveyor-type screen. Both rotating weights and eccentrics are employed in these types, but in all the effect is to produce a deck motion with a component to impart a forward throw.

One type of mechanism for fine screening fits in none of these classifications. This is the turbine type in which a rotating turbine-like slinger situated within a cylindrical screen throws material against the surface so that sufficiently fine material can pass through. Recent improvements in the type, coupled with higher operating speeds, are reported considerably to have extended its field of application.

# Use of Metallic Filter Cloth

*AT THE SUGGESTION of the authors of the preceding article Chem. & Met.'s editors undertook a brief survey of metal filter cloth, its limitations, advantages and applications.*

**M**ANUFACTURERS of metallic filter media lay no claim that these materials are cure-alls for all filter troubles, nor do they recommend them for use where the much less expensive non-metals will do just as well. However, in a good many cases the special advantages of metallic media, including superior resistance to heat and corrosion, and much greater strength, make them more economical on a dollars and cents basis. Comparative economy is the only correct method of determining the choice and when not only the uninstalled costs of the two types of media are compared, but also lost time and the cost of reclothing, certain types of application show up much to the advantage of the metallic materials.

One manufacturer states that the greatest number of installations is in the alkali industry, followed by pulp and paper (not including fourdrinier wire), petroleum refining, and cane sugar refining. International Nickel Co. has published an extensive list covering products that are being filtered through Monel and nickel filter cloths, which includes such materials as organic, mineral, fruit and fatty acids, caustics and brines, animal, vegetable and mineral oils, pharmaceuticals, solvents, black liquor and clays, as well as a variety of other materials. Pyroxylin solutions of varying viscosities are handled rather extensively by this means.

Manufacturers differ considerably in their opinions regarding the degree of acidity which can be economically handled with metallic media. It has been pointed out that the same degree of corrosion that can be tolerated in plate, sheet or cast metal equipment may be entirely unacceptable in a filter medium. Owing to the fineness of the wire used, its surface is very large in comparison with its volume. Since the voids are extremely fine, deposition of the prod-

ucts of corrosion may easily result in the blinding and spoilage of the cloth. Hence it is clear that only actual tests under operating conditions can give a safe basis for recommendation.

Metal fabrics are of two general types; the so-called wire cloth and screen which is used for screening, sieving and bolting; and metallic filter cloths which are a specialized form, developed particularly for filtration. The coarser weaves are used with diatomaceous earth and other filter aids, while certain finer types can generally be used directly, without an auxiliary means for building the cake. Almost any metal that can be drawn into wire can be used, those most commonly employed including: Monel, nickel, 18-8 stainless, copper, brass, phosphor bronze, tinned metals and aluminum. Such alloys as KA2SMo stainless and Everdur are also used.

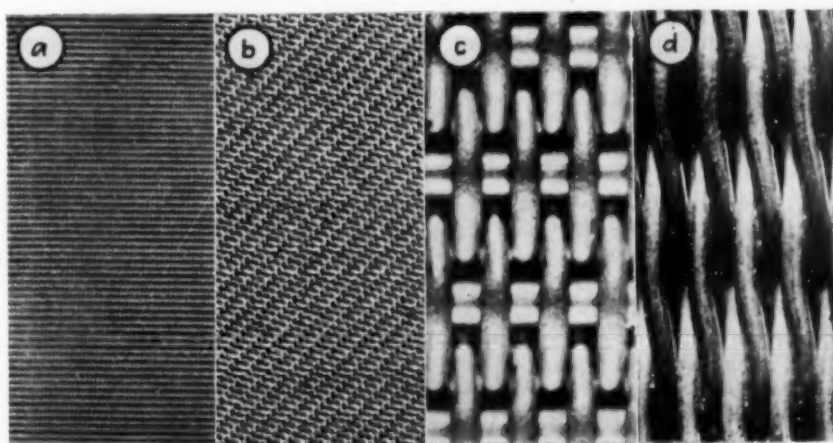
There are two basic weaves and several modifications used for filtration. The ordinary square mesh is sometimes employed where coarse filter aids such as asbestos or paper pulp are used, but to produce a fine

weave in this type requires fine wires and gives a cloth of low strength. The object of the specialized weaves, therefore, is to permit the formation of extremely fine flow passages without the use of exceptionally fine wire and without loss of strength.

Of these basic weaves, the "dutch" or corduroy is the simpler. Illustration (c) shows such a weave. It is of the "over-one, under-one" type with the warp wires straight and uncrimped, and the filling or "shoot" wires pushed as closely together as possible. A stronger modification is to use multiple warp wires laid side by side. The second basic weave is the twill which is a "over-two, under-two" weave, giving a characteristic diagonal pattern. Twills may be of single wires (not illustrated), of multiple wires forming a stranded or basket-weave twill (illustration b), or a dutch weave twilled as in illustrations (a) and (d). In this last, since as in the plain dutch weave the warp wires are not crimped, the "over-two, under-two" scheme is followed only with the filling wires, resulting in an extremely dense weave. As in the plain dutch, multiple warp wires can be used for extra strength if desired. Types (a) and (b) have generally similar uses, often without filter aids, while type (c), being less dense, is intended for filter aid use.

Most of the information incorporated in this brief survey was supplied through the courtesy of the W. S. Tyler Co., the Multi Metal Wire Cloth Co. and the Newark Wire Cloth Co. The first of these concerns supplied the natural size photographs, and the second, the photomicrographs.

Typical metallic filter media: (a) 28x496 dutch or corduroy twill, natural size; (b) 36x36 stranded or basket weave twill, natural size; (c) plain dutch weave x 16 magnification; (d) dutch twill x 16 magnification



# Super-Filtration by Dialysis

BY H. P. BASSETT, president of Meigs, Bassett & Slaughter, Philadelphia chemical engineering consultants, who has recently been devoting much of his attention to the applications of dialysis. During the War Dr. Bassett distinguished himself for his work on nitrocellulose. More recently his work on rayon has been well known.

RECENT EXTENSIVE APPLICATION of dialysis to the purification of waste caustic soda in the rayon industry has focussed attention on the possibilities for accomplishing difficult or otherwise impossible separations by means of this heretofore little used method. Really a process of super-filtration by which it is possible to separate crystalloids from colloids, and even possible to separate crystalloids on the basis of molecular size, dialysis has suffered from a confusion of terms wherein it has been mistaken both for osmosis and simple diffusion. It is advisable, therefore, first to clear up such misconceptions.

When a solid or liquid dissolved in a solvent is separated from a quantity of the solvent by a suitable membrane and the solvent passes through this membrane, diluting the solution, this phenomenon is called "osmosis." When, however, a material is dissolved in a solvent and a movement of the particles occurs from the place where the solution is more concentrated to a place where it is less concentrated and continues until the concentration is uniform throughout, this transfer is called "diffusion." Finally, when the diffusion of a liquid is accompanied by either partial or total separation of unlike bodies, the term properly applied to the separation is "dialysis." It is this last phase in which the chemical engineer is most interested. Dialysis as a commercial operation is generally carried out through the use of some kind of colloidal membrane, diaphragm or septum.

The laws and conditions governing dialysis were determined more than

75 years ago by Graham and others who were laying the ground-work for colloid chemistry. Without using a membrane, in 1850 Graham was the first to measure the rates of diffusion of a variety of compounds. Among other things, he showed that the quantity of a substance diffused in a given time was proportional to the concentration of the original solution. A little later Fick was able to state that the quantity of salt that diffuses through a stated area is proportional to the difference between the concentrations of two areas, infinitely close to each other. In Graham's later work he found that a fairly complete separation of two salts occurred when there was a considerable difference in their rates of diffusion, and that this difference depended on molecular weight. He found widely varying diffusion rates among various substances, some of which such as gums, tannins, albumins and caramel, were extremely slow and did not usually assume a crystalline form. Comparing a number of materials, he found that the time required to accomplish the diffusion of one mole was in the ratio of 1 for HCl, 2.3 for NaCl, 9 for MgSO<sub>4</sub> and 99 for caramel.

Other work by Kohlrausch and Nernst showed that the rate of diffusion into a colloidal jelly was proportional to the square root of the time during which diffusion had already taken place. These early investigators found that allowing substances to diffuse into a jelly or other colloidal form of matter eliminated convection currents and other mechanical disturbances and so improved the means for studying liquid

diffusion. Later it was noted that a colloid would allow the diffusion of a crystalloid, while it inhibited the diffusion of a colloid. Hence, this method came into use, through the employment of vegetable membranes such as parchment paper, or animal membranes such as pig's bladder.

By the assistance of membranes, then, Graham and others studied the preparation of many jelly-like inorganic colloids such as aluminum hydroxide, iron hydroxide, stannic acid and copper ferrocyanide, which could thus be completely separated from the precipitating agent.

## Membranes and Diaphragms

In the foregoing it has been implied that in dialysis through a membrane, the membrane serves as a sort of super-filter, the openings of which are large enough to permit the passage of small molecules in solution, while they retard or completely prevent the passage of larger molecules and colloidal particles. The membranes used in dialysis are themselves colloids, among which may be mentioned such materials as parchment paper, Cellophane and similar regenerated cellulose films, cellulose acetate, collodion and casein films, formaldehyde-hardened gelatine and glassine paper. Mercerized cotton fabric diaphragms have also been used. The efficacy of a membrane material for a particular application appears to depend not only on its strength and thickness, which must be sufficient to withstand the necessary mechanical strains, and its chemical resistance to the materials undergoing separation, but also on the colloidal structure. The more

nearly the film approaches a true colloid, the faster the rate of flow that is possible through it, and the more complete the separation of the constituents of the solution. It appears that the rate of precipitation of the film material controls the size of its molecular particles and hence the rate of diffusion which can be attained through its interstices, as well as the size of particles which can pass through.

The ideal diaphragm material is one which is completely colloidal, but is still strong enough to withstand a considerable fluid pressure when wet, and is unaffected chemically by the materials being handled. Microscopic examination of parchment paper shows that some of the fibers have not been acted on in the process of parchmmentizing, and hence are not in the desired form for dialysis, constituting a loss of effective area. The same is true of mercerized fabric diaphragms. On the other hand, such examination of Cellophane shows it to be truly colloidal. Collodion films closely resemble Cellophane in this respect. At present, however, precipitated films of this sort are relatively low in mechanical strength and it seems not unlikely that success may be attained in the development of a composite membrane material produced by precipitating viscose, cellulose acetate or other colloidal film on to a coarse mesh of cotton, the latter serving as a reinforcement without materially reducing the effective area. That ability to withstand fluid pressure is an important consideration will be evident from the fact that one investigator found an in-

crease in dialyzing speed of four, in increasing the pressure differential across the diaphragm by 15 lb. per sq. in.

Although most of the early work on dialysis was carried on by researchers in pure chemistry, it remained for engineers to commercialize and investigate the possibilities of the process. So far most of this development has been in the recovery of waste caustic soda in the rayon industry. One of the earliest patents, that of F. H. Griffin of the American Viscose Co., dealt with a cloth diaphragm parchmmentized with sulphuric acid to produce a film of colloidal hydrocellulose, filling the interstices in the fabric. In Italy, L. Cerini mercerized special cotton fabric with high strength caustic, but later impregnated the cloth with insoluble soaps and salts of colloidal nature. Attempts have been made with considerable success to support such films as Cellophane and parchment paper on a wire mesh, but this of course does cut down the flow.

Another different approach was that of Shozo Tachikawa, in Japan, who attempted to overcome the defects of very thin unsupported parchment paper by equalizing the pressure on the two sides, so as to offset the osmotic differential. The method accomplished its purpose in one respect, but offset it in another, since by eliminating the pressure differential, and the consequent increase in diffusion rate, the advantage of a thin diaphragm was lost. A number of these dialyzers have been installed in the United States, but their thin parchment diaphragms have been replaced with a 30-lb. parchment which appears to have the necessary strength and at the same time, guards against minute holes which would pass hemi-cellulose.

(Equipment for carrying out dialysis has been developed in several countries. With the exception of a more recently commercialized American unit of the filter press type, all principal machines were described by H. B. Vollrath in an article in *Chem. & Met.*, June, 1936, p. 303.—Editor.)

#### Uses for Dialysis

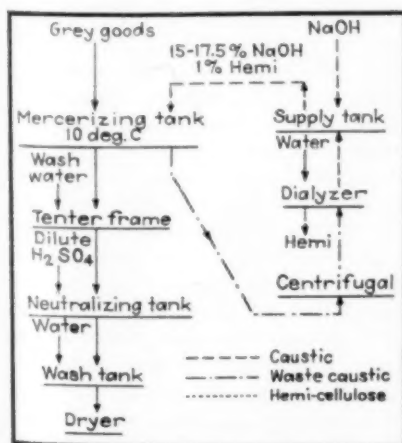
Probably the first commercial application of dialysis was in the beet sugar industry where the extraction of crystallizable sugar was accomplished by diffusion through the natural diaphragms formed by the beet

cell walls. Parchment thimble dialyzers were also used in the separation of sugar from the final molasses. The drug and pharmaceutical industries then seized on dialysis as a means of purifying certain drugs such as agar-agar, certain alkaloids, and biological serums. Many of these purifications would be impossible by other means. Parchment paper and Cellophane have been the materials most used for these purposes, although many other of the materials mentioned above appear to have excellent possibilities.

By far the most extensive application of dialysis to date is that in the viscose rayon and wrapping film field. A number of years ago economies were clearly in order and it became evident that dialysis would not only save money but would assist in producing a more uniform and a better product. Formerly the rayon industry had either sold its waste steeping caustic to soap manufacturers, or had evaporated and incinerated it for the recovery of the alkali. Dialysis was early considered, but apparently not very seriously, as were processes of precipitating the hemi-celluloses and other cellulose derivatives by freshly precipitated cupric hydroxide, and of oxidizing the unwanted ingredients by means of an agent such as  $H_2O_2$  and a catalyst. Later it was recognized that a small amount of hemi-cellulose (not over 1 per cent) was desirable in the steep liquor to enhance the flexibility and soft hand of the product. It was found that 99 per cent alpha-cellulose linters gave the desired wet and dry strength, but not the necessary softness, whereas, with wood pulp and proper control of the hemi, a soft, flexible product resulted. Working in this direction, the industry employed cotton linters, usually mixed with wood pulp, but in the meantime, the pulp manufacturers were developing a higher grade pulp. Where pulp originally ran 83-84 per cent alpha-cellulose, it is now available with an alpha content of 91-94 per cent. Since the linters-pulp combination did not give the desired finish, the trend in recent years has been sharply toward an increased percentage of this higher grade pulp. The new pulp made important strides toward the desired hemi balance, but there was still about 10 per cent of the total caustic to be recovered. Dialysis proved the answer, for it permitted a ready separation

(Please turn to page 285)

Suggested flow sheet for purifying waste mercerizing caustic



# Trends in Centrifugal Separation

BY CHARLES M. AMBLER, JR., chief chemist for the Sharples Specialty Co., Philadelphia, Pa., who has for the past nine years been engaged in developing new uses and expanding the field for centrifugal equipment in chemical and related industries.

A CENTRIFUGAL, or a centrifuge, is in the broadest sense a mechanical apparatus designed to generate and utilize centrifugal force, i. e., the tendency of a rotating body to flee from its center of rotation. Through custom this definition has been narrowed to cover only equipment which, by the utilization of centrifugal force, is designed to accomplish: (1) The separation of immiscible liquids, such as oil and water; (2) the removal and recovery of solid particles which are dispersed in a liquid; or (3) the removal of excess liquid from contact with solids.

Centrifugals are divided into two broad classifications according to their function. One type which employs a solid-wall rotating cylinder may be described as a settling machine in which centrifugal force is substituted for the action of gravity. The other utilizes centrifugal force to remove free liquid from solids supported on the surface of a perforate cylinder. This has been considered by some as a centrifugal filter. In reality, however, centrifugal force is utilized to throw the drops of liquid off the solid particles while the latter are held back by the basket wall.

History fails to record the earliest uses of centrifugal force for such purposes. One authority mentions its use in connection with the clarification of tung oil many centuries ago by the Chinese. However, modern industrial application dates only from the middle of the last century. But in recent years a vast fund of accumulated knowledge has been built up by the constant exploration of centrifugal manufacturers into new fields. By continuous testing and development, not only has the

field of application for centrifugals been constantly expanded, but the cost per unit of material processed, the production man's yardstick, has been constantly reduced. Improvements in design and construction have also improved performance and reliability with greater assurance of quality and uniformity of product.

It is the purpose of this article to survey the various types of centrifugals now available and to indicate their several mechanical features and, to an extent necessarily limited by the space available, their suitability for specific applications.

Subsidence in any system takes place according to Stokes Law which states that the velocity of sedimentation of a particle is proportional to the square of its radius, to its relative density with respect to the fluid medium in which it is suspended, and to the accelerating force. In practice, the results obtained from centrifuging depend on the effective mass of the particles in the dispersed phase, the viscosity of the medium through which these particles must move, the time they are subjected to centrifugal force, and the centrifugal force itself.

The centrifugal force developed in a rotating cylinder is proportional to the product of its radius and the square of its rotational speed. Mathematically this is expressed as  $F = K N^2 r$  in which  $F$  is force "times gravity" and  $K = 0.0000284$  when  $N$  equals revolutions per minute and  $r$  is the radius in inches. The stress in the wall of this rotating cylinder is proportional to the square of the peripheral speed (that is, to the square of both the rotational speed and the radius). Hence, for a

given strength construction material, the smaller the diameter the greater the centrifugal force that may be generated without danger of rupturing the cylinder.

A 2-in. diameter Super Centrifuge rotated at 50,000 r.p.m. develops a separating force of 62,500 times gravity, while a 48-in. diameter basket centrifugal rotating at 750 r.p.m. develops a separating force of approximately 400 times gravity; yet in both cases the unit stress in the bowl wall is approximately the same. The basket centrifugal is adapted to the removal of relatively large proportions of coarse material or solids from suspension in liquid but, owing to its low centrifugal force, complete clarification of the liquid medium is seldom obtained and the solids are packed to only a relatively low concentration for this same reason. In contrast, the 2-in. Super Centrifuge is designed to permit substantially complete removal of very finely divided solid material, such as bacteria, which are visible only under a microscope. On the other hand, the basket centrifugal has a total volumetric holding capacity of some 90 gal., while the 2-in. high-speed centrifuge has a holding capacity of only slightly over  $\frac{1}{2}$  pt. But for equivalent completeness of separation done in the processing of materials that are relatively difficult to handle, small-diameter, high-speed centrifugals usually have a much higher capacity than large-diameter, low-speed bulk machines. This is reasonable because since sedimentation occurs at an angle to the liquid flow that may approach 90 deg. in a continuous centrifugal system, the velocity of sedimentation must be great

enough to separate out the dispersed phase during the time the liquid is being subjected to centrifugal force. Hence, for any given system the rate of throughput of liquid has an important bearing on the degree of separation or clarification.

Both types of centrifugal have their own specific uses in all three of the fields to which such equipment is applied, and the proper selection of the type and size for any problem must be based on a complete knowledge of the properties of the material to be processed and of the particular capabilities and uses of the various types of centrifugal.

As already noted, centrifugals can be classified according to the means provided for the removal or recovery of the separated phases, but an arbitrary arrangement on the basis of the centrifugal force used in accomplishing this separation is more convenient and understandable, and is used here.

#### Laboratory Centrifugals

**Batch Type**—In the conventional laboratory bottle centrifugal the material to be centrifuged is charged into the bottles by hand, the bottles spun for a predetermined period of time, stopped and the clarified liquid decanted or siphoned off by hand. The sedimented solids and precipitates may then be either scraped or washed out. Many different types of bottles or containers are available for measuring the volume of the separated solid or liquid phases as well as for facilitating their recovery.

In the conventional design speeds

up to 2,500 r.p.m. on an 8-in. peripheral radius are available. Special high-speed bottle centrifuges have been constructed which rotate at up to 8,000 r.p.m. for the exact determination of small quantities of moisture and sediment in oils. These units may be electric-motor or steam-turbine driven.

**Ultra Centrifuge**—This is a device designed to permit observation through an optical system of the progress of sedimentation under theoretically ideal conditions. This instrument is used for the determination of molecular weights and particle sizes by recording photographically the changes in concentration over timed intervals. Its rotor is operated either in vacuo, or in an atmosphere of low pressure hydrogen, to avoid generating frictional heat on the rotor surface, which would set up convection currents in the material being tested and thus interfere with the results. Ultra Centrifuges are constructed with both oil- and air-turbine drives. They operate at speeds up to 100,000 r.p.m. on a 2-in. radius and develop up to 500,000 times the force of gravity. Modifications have been devised to permit direct microscopic observation, and for other biological research applications. All of these machines are of the batch type, for the treatment of limited volumes.

**Continuous Type**—Continuous liquid discharge Super Centrifuges which rotate at speeds up to 50,000 r.p.m., developing 62,500 times the force of gravity, permit the clarification or separation of larger quantities

of material with high efficiency. These units are equipped with interchangeable clarifier, separator or batch rotors, or bowls, constructed of a variety of corrosion-resistant metals. The liquid to be processed is fed continuously to the bottom of the rotor and the purified or separated liquids discharge from the upper end into stationary covers. The sedimented solids are held within the bowl and are periodically removed by hand. By minor modifications in design and suitable operating technique this type may be used for classification and determination of particle size of suspended solids, and even for the concentration of proteins and similar molecules existing in true solution.

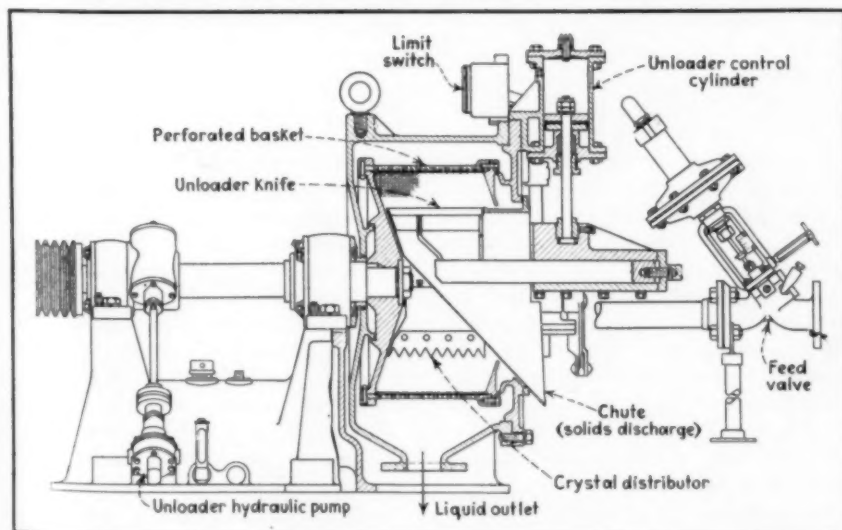
#### High-Centrifugal-Force Centrifuges

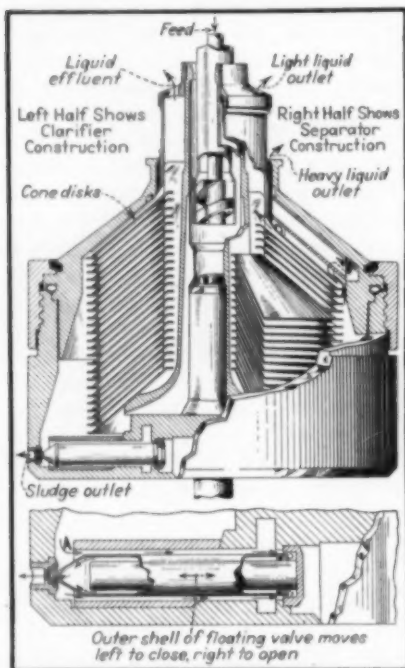
Commercial high-centrifugal-force centrifugals have an advantage over other types of separating equipment in that they can be made continuous in operation; separation is accomplished quickly so that undesirable effects such as reactions and spoilage are avoided. Such equipment occupies little space and give exceptionally complete separation.

Two main types of high-centrifugal-force centrifuges are in general commercial use for continuous clarification and for the separation of immiscible liquids. These are the long tubular bowl type and the disk bowl type. The tubular type is characterized by a rotor relatively long with respect to its diameter. In this type the highest centrifugal force commercially available, 13,200 times gravity, is generated by the rotation of a 4-in. diameter bowl at 15,000 r.p.m. The rotor is suspended from either a turbine wheel or a pulley which is belt driven from an electric motor.

Liquid to be processed is fed into the bottom of the rotor and during its flow upward is subjected to centrifugal force. Any solids present are sedimented against the bowl wall out of the path of the liquid and are periodically removed. In clarifying a single liquid the clarifier type of bowl with a single discharge is used. For separating immiscible liquids a separator bowl constructed with a baffle at the upper end is used. The heavier liquid flows out over a weir, commonly known as a ring dam, which may be adjusted for different specific gravity ratios in the liquids being centrifuged. In the tubular bowl, a simple interior vane or three-wing is provided to keep the

Sharples Super-D-Hydrator effects automatic bulk operation at full speed (2,000 r.p.m.). A simple automatic timer operating on an adjustable cycle controls the loading, rinsing, drying and discharging functions





DeLaval Purifier bowl showing new floating valve slurry discharge in detail. The valve is closed by centrifugal force and a small amount of liquid constantly flows out the minute orifice, but when opening A is clogged with sludge, the valve drains and is forced open, allowing sludge to discharge

liquid rotating at full bowl speed and prevent loss of efficiency due to swirling.

This type of centrifugal lends itself to adaptations for specific purposes such as operation under pressure, in vacuum, in contact with an inert gas, and with recirculation of a volatile solvent in order to prevent deposition of solids on the rotating surfaces. Over 100 different types of rotors have been constructed to permit correct solutions of upward of 700 different operating problems. The tubular bowl, because of its small diameter and simplicity of design, may be constructed of corrosion-resistant materials such as Monel and stainless steel, in cases where iron would be rapidly attacked or have a detrimental effect on the material in process.

The disk type of bowl is characterized by being relatively short with respect to its diameter. It is usually fed at the top and the separated liquids discharge from approximately the same elevation at somewhat greater diameter. The conventional drive is from a motor through a gear and worm located under the rotor. Because of the somewhat lower centrifugal force which can be developed

by this machine (7,000 times gravity for the 12-in. diameter size running at 6,400 r.p.m.), the incorporation of a series of conical disks to stratify the liquid is usually necessary to obtain satisfactory operation, although they may introduce a serious cleaning problem. This type of centrifugal is also supplied with rotors for both clarification and separation. It may be obtained in sizes from 4 in. to 24 in. in diameter and is applicable in general to the same problems as the tubular type.

*Self-cleaning centrifugals*, another common type of high-centrifugal-force machine, reduce operating labor cost at the expense of increased initial investment and higher power demands. In addition, the type of solids which may be continuously discharged is limited to amorphous materials which will not pack or bridge an opening and in general to non-abrasive materials.

One type of self-cleaning rotor is the peripheral orifice bowl. It is fitted with a series of nozzles or orifices at the periphery of the bowl, through which a portion of the liquid fed to the rotor continuously leaks out, carrying with it the sedimented solids. Since this is the point of greatest pressure in the system, it is necessary to keep the nozzles quite small in size to prevent excessive discharge of liquid. By turning the sludge discharge ports toward the axis of rotation, the pressure on the nozzle can be greatly reduced and larger openings used. This type of centrifuge has found its greatest use in the concentration of yeast. It is adapted only for the continuous discharge of solids of too small size to clog the nozzles, which do not tend to pack at relative low concentration. The power requirement is proportional to the volume of liquid discharged through the orifices, and any increase in their size due to wear or abrasion will increase the power demand as well as decrease the concentration of the sludges discharged.

Another characteristic is that discharge of the sludge is limited to several points on the circumference of the rotor and, therefore, some of the solids must move half the distance between the orifices to be discharged. Sludge that will not flow readily cannot be handled in rotors of this type. However, another type of rotor with a full circumferential opening is available for such cases. This centrifuge bowl is composed of two sections operating as a piston

within a cylinder. Normally the two sections are sealed by spring pressure which can, however, be counterbalanced by a stream of water when desired. The hydraulic pressure of this water is used periodically to expose an annular slot around the periphery of the bowl through which accumulated solids are flushed. The unloading operation may be manually controlled or operated by solenoid valves on a time cycle. In this type of bowl both the solids and any free liquid in the bowl at the time of opening are flushed out.

Bowls of the peripheral orifice type have been constructed in which the orifices are replaced by larger openings normally sealed with valves. In one case the valves are located inside the rotor and weighted by the liquid being centrifuged. The valve is perforated so that liquid slowly flows through. Eventually the entrance to the valve chamber becomes sealed by accumulated solids, and when the liquid in the valve leaks out thus diminishing the pressure, the sludge forces the floating valve open and flows out through the orifice. When the valve again fills with liquid it re-seats itself and the cycle continues. Due to the lag in the motion of the valve the sludge discharges at relatively low concentration.

One modification of the peripheral orifice bowl which has been successful in handling such diverse substances as starch and well-drilling mud permits recycling a portion of the sludge back through the rotor for additional purification. At the same time a portion of the recycled stream of concentrated sludge is continuously drawn off. This machine has an advantage over other nozzle bowls in that while wear increases the power demand, it has little effect on the concentration of the sludge.

"Flotation" may be used for the removal of solids from the rotor in some cases. An instance is the removal of amorphous wax from a chilled solution of lubricating oil stock in naphtha. It is possible to float this wax out of the bowl continuously on a stream of carrier liquid, in this case brine.

A special design of continuous solid discharge bowl has been developed for removing crystalline wax from lubricating oil stocks. In this case the oil is dissolved in a chlorinated hydrocarbon selected so that the resulting solution will be heavier than the wax which precipitates from it at low temperature. Under centrifugal force the

wax goes to the center of the bowl and is continuously removed by a decanting horn.

The above discussion has been limited to centrifugals falling into the category of settling machines, i.e., the solid-bowl types. Some attempts have been made to incorporate filters and screens into high-speed centrifuges, but these have been unsuccessful.

#### Bulk Centrifugals

**Batch Type**—Most of the large-diameter basket bulk centrifugals of relatively low speed are adaptable for use as either settling machines or centrifugal dryers, in the former case using solid wall rotors, and in the latter case, perforate baskets. While from the point of view of the unit operations there is a rather wide difference between centrifugal drying and centrifugal sedimentation, in the mechanical aspects of the centrifugal the difference is a minor one.

This type of centrifugal varies in size from 12 to 80 in. in diameter and the centrifugal force generated varies from 250 to 2,000 times gravity.

Early use of the bulk centrifugal was made by Weston for the rinsing and drying of sugar, and today its largest use is in sugar refining. Conventional basket centrifugals rotate on a vertical axis and may be either suspended from or mounted over the drive. The first type employs direct, gear, or belt drive, while the second generally is belt driven. The same type of mechanism may be used with a solid wall rotor for clarification, in which case the rotor is provided with baffles to prevent short circuiting of the liquid flow and to promote more efficient clarification. Clarified liquid in this type discharges over the lip

ring, while the solids are removed periodically by slowing down and flushing.

When processing bulk material the use of the overdrive type is usually recommended since the basket can be supplied with an open bottom and a hand operated scraper to perform the unloading operation with a minimum of labor. For drying textiles, laundry, etc., the underdrive is more suitable, since more space is available for packing the product in by hand. In operation the vertical bulk centrifugal is loaded at relatively low rotational speed and not brought to full speed until the bowl or basket has been fully charged. For unloading the basket must be brought to a full stop if hand work is employed or to almost a full stop if the mechanical scraper is used. In some cases, semi-automatic means have been employed for controlling the cycle.

**Automatic Bulk Centrifugals** — Many modifications of the bulk centrifugal have been introduced in order to reduce operating labor and improve performance and operation. Most of these involve the rotation of the bowl or basket on a fixed axis so that the sludge or cake can be scraped out with a mechanical cutter and dropped into a chute leading away from the rotor. The most modern construction involves rotation on a horizontal axis so that the solids can be removed by the cutter knife with the bowl rotating at full speed, thus achieving virtually continuous operation. Like the vertical machines, the horizontal bulk centrifugals employ a perforate basket for removing excess liquids from solids, or a solid-wall basket for clarification. In the latter type the liquid

is removed through a decanting horn to minimize splashing and avoid liquid leakage down the chute.

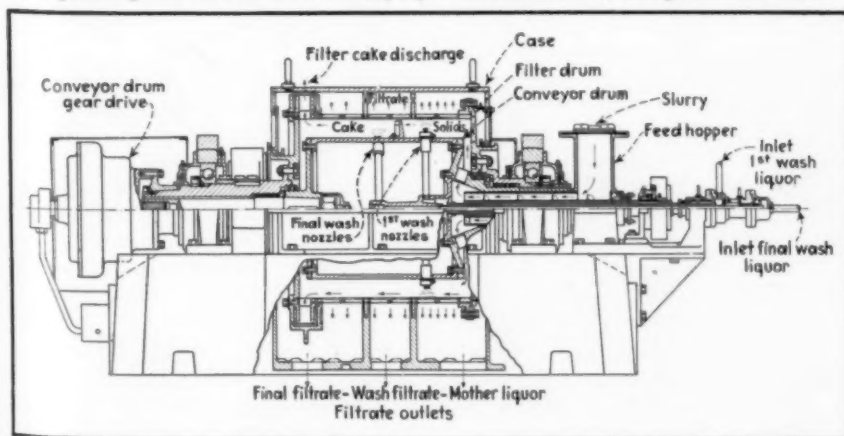
Among the newer developments which couple flexibility with good performance is a 20-in. diameter unit designed to rotate at 2,000 r.p.m. Any part of the operating cycle of this centrifugal may be lengthened or shortened as desired to obtain time for applying the required amount of rinse water and for drying. It handles 50 lb. of byproduct ammonium sulphate on a 45-sec. cycle, during which the bowl is loaded, the crystals rinsed, dried and unloaded with the rotor running continuously at full speed. Entirely automatic, labor-free operation is effected by an interlocking system of pneumatic and hydraulic valves controlled from an electrically synchronized panel board.

Another type of automatic bulk centrifugal offers continuous operation based on the principle of two rotating bowls. An outer bowl carries either a screen for draining crystals or is of solid plate for sedimentation. An inner bowl rotating at a slightly lower or higher speed carries plows or a continuous helix for forcing the solids across the face of the outer member.

A bulk decanter of the vertical type in which a 42-in. diameter rotor runs at 1,900 r.p.m. is used for the concentration of sewage sludge. Owing to its vertical axis it is necessary to drop the speed to 50 r.p.m. in order to effect automatic mechanical unloading. In this unit the complete cycle is automatically controlled.

In tracing the types of centrifugals available, from the smallest to the largest, the greatest stress has been laid on the more modern mechanical developments. These developments, together with metallurgical advances in construction materials, particularly with respect to improvements in corrosion-resistant metals, have contributed much to the expansion of the field of application of centrifugal equipment in recent years. Too great stress cannot be laid on the value of proper pretreatment of the materials to be processed centrifugally, including proper preheating, premixing, proportioning and presettling with whatever auxiliary equipment may be required to accomplish these steps. It is in this field that possibly the greatest advancements have been made, based on the accumulated knowledge and correlation of data secured from a great variety of fields by the centrifugal manufacturers.

Bird continuous centrifugal of the automatic bulk type. It consists of two bowls rotating at slightly different speeds, the outer one performing the separating and the inner one carrying a helical knife to scrape off the cake



# Technique of Settling Separations

BY ANTHONY ANABLE and CHESTER L. KNOWLES, chemical engineers, who have long been associated with the Dorr Company, New York. Mr. Anable edited the Mechanical Separations section in Perry's "Chemical Engineers' Handbook". Dr. Knowles is a leading authority on heavy chemical, paper pulp and pigment processes.

MOST IMPORTANT among the separations depending on gravity settling, thickening, hydroseparation and classification are keystones in the structure of mechanical processing. Their field of application includes the manufacture of such heavy chemicals as alum, phosphoric acid, caustic soda, and blanc fixe; such pigments as lithopone, whiting, titanium dioxide, and ochre; the beneficiation of bauxite, phosphate rock and cement rock; the treatment of industrial wastes and the purification of industrial water supplies—not to mention the concentration and extraction of most precious and base metal ores.

The purpose of this article is not merely to describe the equipment employed. That has been done adequately before. Rather, it is the intention of the authors to delve briefly into the principles and phenomena underlying the unit operations themselves, to explore their places in a number of different flow sheets and, finally, to recount some of the physical and chemical considerations which in any given case govern the operating results obtainable and the unit costs for specific jobs.

Thickening, or sedimentation, to use the generic term, is the gravitational settling of the solid particles that are suspended in a liquid. In essence, it is the removal of the bulk of the liquid from the bulk of the solids under the influence of gravity alone. Stokes Law for spherical grains, as given below, is of little practical value in thickening calculations but is of interest here because it shows what factors have an effect on the settling rate or terminal velocity

of a particle and the relative magnitude of the various effects. This formula is  $V = 3,246 D^2 (d_s - d_l)$ , where  $V$  = terminal velocity, in cm. per min.;  $D$  = diameter of the spherical grain, in mm.;  $d_s$  = density of the solid, as sp. gr.; and  $d_l$  = density of the liquid, as sp. gr. Here 3,246 is a constant.

Stokes' formula, unfortunately, deals only with free settling particles, whereas in the process industries particles are often originally in physical contact with one another and this is always the case in the final or compression zone of sedimentation. The actual test procedure in use today is based not on the work of Stokes, but on that of Coe and Clevenger and later of Deane, who showed that for any zone of settling between feed and discharge dilution the settling area required can be expressed as  $A = 1.33 (F - D) / R$ , where  $A$  = settling area in sq. ft. per ton per 24 hr.;  $F$  = feed dilution (i.e. ratio of liquid to solids by weight);  $D$  = final dilution; and  $R$  = settling rate, in ft. per hr.

To use this formula, tests must be made to determine the settling rate,  $R$ , in zones ranging from feed to discharge dilution and the maximum unit area,  $A$ , which, in turn, will determine the size of thickener.

This is a very sketchy outline of sedimentation theory. In no case should settling tests be entrusted to those inexperienced in the art. Not only is there a definite and precise technique that must be followed, but also the experienced investigator will know how to alter the physical, chemical or thermal conditions of an obstinate pulp to improve its

settling characteristics and reduce the size and cost of a station.

Few chemical engineers appreciate what can be done by proper application of test procedure and physico-chemical principles to make an apparently unseizable pulp settle rapidly and yield a crystal-clear overflow and a dense sludge. A change in temperature of 10 deg. C. in certain cases has changed capacity 100 per cent. Mechanical or chemical flocculation causing minute particles to coalesce, correction of the pH, liberation of the electrostatic charges, or recirculation to promote crystal growth may completely alter the settling characteristics. Furthermore, temperature control, eliminating convection currents and their injurious effects, or a special system of revolving, vertical fingers, releasing liquid occluded in the sludge, yields a denser, more compact discharge than is obtainable in any other way short of filtration.

**Continuous Thickeners**—The Dorr thickener, of which there are several types, consists essentially of a shallow, cylindrical settling tank, equipped with a central feed well, a peripheral overflow collection weir, a pump-regulated sludge discharge outlet at the bottom and a raking mechanism for plowing the settled solids gently to the sludge outlet. Both single- and multiple-compartment thickeners are used, the latter type when built with trays in parallel being equivalent to a single thickener of much greater floor area. With trays in series the multiple-compartment type is equivalent to a complete counter current decantation plant in a single compact unit.

**Scope and Limitations**—The size of a thickener must be such that the solids contained in the slurry fed to it will drop out of suspension before the liquid constituent reaches the peripheral overflow weir. This is a matter of correct testing before specifying size and of proper control of operating conditions.

Thickening never completely separates all of the solids from all of the liquid, although the rabbling action of the rakes does remove a certain amount of occluded water and one decantation in a continuous thickener is usually regarded as the equivalent of about one and one-half decantations in a batch settling tank. Filtration followed by drying must be added to thickening to make 100 per cent separation. In a hypothetical case the first step, thickening, might reduce the feed dilution from 20:1 to 1:1; while the second step, might carry it from 1:1 to 20 per cent moisture (dry basis); and drying, the third step, from 20 per cent to dryness.

It is definitely cheaper to remove excess liquid by thickening rather than by filtration; just as it is definitely cheaper to remove liquid by filtration than by drying. Broadly the unit costs of filtration and thickening are in the ratios of between 4 and 8 to 1. This is of great importance because, generally, the largest proportion of the total liquid can be removed in a given case by

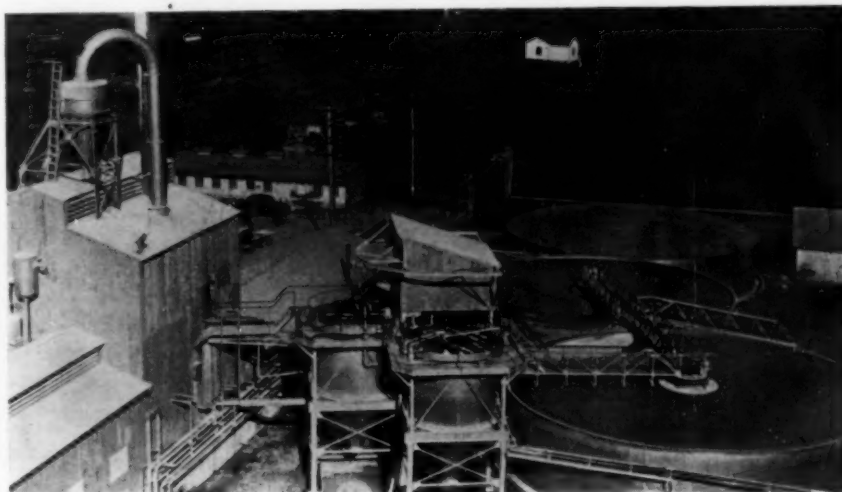


Fig. 1—Two Dorr thickeners clarifying raw brine at a chemical plant which makes magnesium products from natural brines

the cheapest of the three unit operations—thickening. In our hypothetical case the three steps remove respectively 95 per cent, 4 per cent and 1 per cent of the liquid.

A filter gives maximum capacity and lowest cost on a pre-thickened feed, just as does a dryer on a filtered feed. Furthermore, a material that filters and dries readily will usually thicken readily. Consequently, the lowest unit dewatering cost will generally be found with the thickener-filter-dryer combination, each element of which is allowed to operate only over its most efficient and most economical range

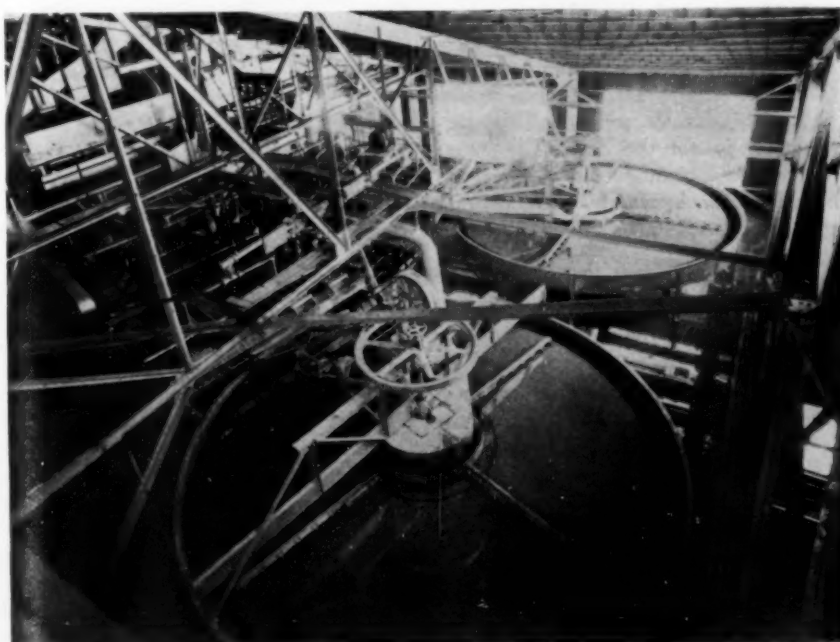
and passing on an ideally conditioned feed to the next step.

**Relative Costs**—There are probably today more continuous thickeners and continuous vacuum filters installed for the cyanidation of gold and silver ores than in the entire chemical industry. Results are unusually uniform and operating and cost data are remarkably complete. A citation of data from this field should therefore be useful in considering the merits of a combination of thickeners and filters as the ideal dewatering station.

Gold quartz ore, wet ground to 95 per cent minus 200 mesh, has a unit area of between 5 and 7 (i.e., 5 to 7 sq. ft. of thickening area is required per ton of ore per 24 hours). The feed to the thickener is at a dilution of between 2 and 3:1, final discharge dilution is 1:1 and at a 500-ton-a-day mill, the overall thickening costs approximately 1.5 cents per ton per step of thickening. Corresponding figures for vacuum filtration are: Feed dilution 1:1, cake moisture 25 per cent, overall cost 7.5 cents per ton per step of filtration. In practice, the flow-sheet most often used consists of three decantations followed by one stage of filtration and less frequently, four decantations without filtration or one or two decantations followed by two stages of filtration. The unit cost per stage favors thickening 5:1.

In the chemical field, calcium carbonate, precipitated in the lime-soda process of caustic soda manufacture, can be thickened from 10:1 to 55 per cent moisture with a unit area, under controlled conditions, as low as 5 to

Fig. 2—Two bowl classifiers operating in closed circuit with tube mills in a wet process portland cement plant



7 sq. ft. per ton per day. Unless properly controlled, the unit area may be as much as 32 sq. ft. or even more. On a 100-ton-a-day basis the unit cost of thickening works out to less than 5 cents a ton per step, while the corresponding figure for vacuum filtration is nearer 25 cents a ton.

Both thickening and filtering costs mount rapidly as the scale of industrial operations is reduced. On small tonnages, the relative unit costs of thickening and filtration may jump to as high as 20 cents and 80 cents a ton respectively. Likewise, the unit area requirements govern the unit costs: the slower the settling rate of the material the larger and more costly is the equipment.

**Thickener Performance**—To the uninitiated the gravitational subsidence of a pulp in a tank would appear to be a simple manifestation of nature's laws, governed, apparently, by a simple formula or two such as those at the beginning of this article. Such is by no means the case and he who blindly attempts to make his own size determinations or adapts figures obtained elsewhere to his own use is courting misfortune and an unpleasant surprise. At least one group of research workers and processing engineers has been studying settling phenomena for three decades and they would be the first to admit that finality has not yet been reached. Here are a few pertinent examples to show how temperamental is the behavior of solids suspended in a liquid, yet how readily they become tractable if given the kind of preconditioning they demand.

**Milk of Lime**—Four different plants in four different parts of the country are slaking burned lime from four different quarries, but doing it in substantially the same manner. Yet the unit settling areas range as follows: (a) 50.2, (b) 64.8, (c) 114 and (d) 142. The unit thickening cost at (a) is about one-third that at (d), due to definite physical and chemical dissimilarities, and had (d) bodily used (a)'s unit area figures as a basis of design, he would have provided only 33 per cent of the thickening capacity he needed. Final dilutions of the four limes above cited vary as widely as do their unit areas and to a certain extent in direct ratios.

**Pigments**—Three different blanc fixe plants yielded unit areas of 1.68, 14.5 and 60. The reason was, possibly, the physical composition of the pigment particles, but more probably the conditions under which they were precipitated, which would have a large influence on particle size and settling rate. Likewise, four samples of clay yielded unit areas of 11.6, 36.2, 56.2 and 330; three different lead pigments were 1.39, 13.2 and 25.10; and four lithopones showed 5.82, 6.45, 15.9 and 30.9. All could be eventually

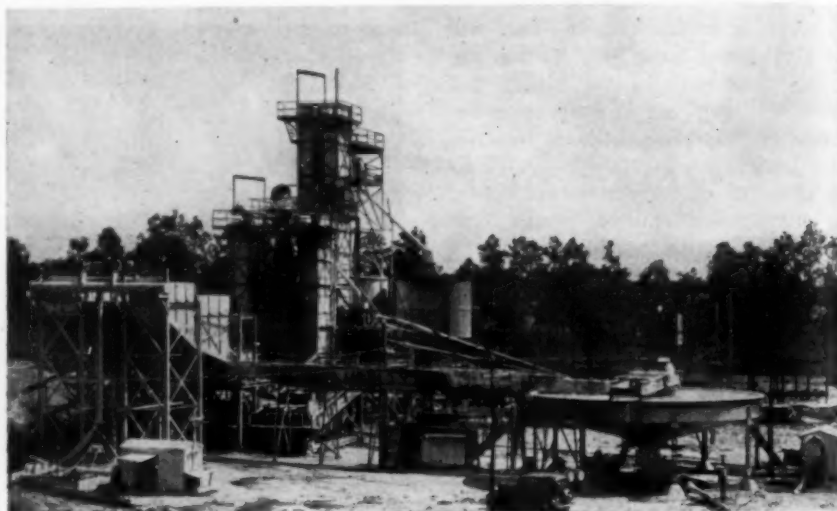


Fig. 3—Dorr hydroseparator at the phosphate rock beneficiating plant of one of the larger manufacturers of superphosphate

settled to about the same final density—1.5:1. Again, not a chance to estimate performance on data obtained from another plant.

**Calcium Carbonate**—Finally, let us examine the behavior of calcium carbonate, a material that should be as devoid of temperament as any to be found in the process industries. In Table I are tabulated the unit areas under three sets of conditions—95 per cent minus 200 mesh calcite, 95 per cent minus 325 mesh whiting, and the carbonate precipitated from the lime-soda process of caustic soda manufacture.

Table I—Unit Areas for Calcium Carbonate

Sample No.	1	2	3	4
Calcite.....	6.4	12	26	44.7
95 per cent -200 M				
Whiting.....	8.7	18.4	26.4	37.
95 per cent -325 M				
Lime-Soda Precipitate	3.26	6.7	17.4	32.2
90 per cent -100 M				

If the eccentricities of the various materials, recounted in the foregoing, were allowed to play a dominant role in industrial operations, there would be real reason for concern. This, fortunately, is not the case. The experienced investigator with a physical-chemical background can control these eccentricities and cause the particles to behave on a limited allowance of unit area.

Where once it was necessary to allow 32 sq. ft. of settling area per ton of precipitated  $\text{CaCO}_3$  per day in causticizing, one can now get by on a pinch with as little as 4 sq. ft.—an 80 per cent saving in equipment. The answer is to slake the lime in a new way to yield coarse particles, coupled with close control of temperature, time and degree of agitation during causticizing.

Once it was necessary to provide a unit area of 40 sq. ft. for thickening

the gypsum precipitated in wet phosphoric acid manufacture. Now sometimes as low as 2 will do it but 10 is usually recommended in order to be sure to remove some of the organic material usually present. Originally a 40-ft. diameter single-compartment thickener had a rated capacity of 40 tons a day; now a 20-footer is good for 200 tons, a 20:1 improvement in settling. Here the improvement was brought about by control at the precipitation station, including, among other things, slurry recirculation.

**Counter Current Decantation**—Continuous counter current decantation (abbreviated as C.C.D.) is the term applied to a continuous system of washing finely divided solids, such as ground ore, chemical precipitates, and residues from leaching operations, in order to free them from liquids containing dissolved substances. In practice, C.C.D. consists of the operation of a series of continuous thickeners so that the solids to be washed pass through them in series, being diluted after each settling by a weaker liquid overflowing from subsequent thickeners in the system and flowing in the opposite direction.

It is the purpose of C.C.D. to attain a high washing efficiency (separation of soluble from insoluble materials) with a minimum number of decantations and with the use of a minimum amount of wash liquid. In practice, the desirable portion of the pulp fed to the C.C.D. system may be the solids, the solution, or, infrequently, both.

The washing efficiency is expressed as the percentage of the soluble salts

in the feed pulp removed as an overflow product from the first thickener in the series.

Consider the following examples of C.C.D. in process industries:

**Aluminum Sulphate**—Bauxite ore, containing  $Al_2O_3$ , digested with sulphuric acid, yields a solution of aluminum sulphate ( $Al_2(SO_4)_3$ ), in which there is suspended insoluble rock residue, chiefly silica. C.C.D. treatment of this pulp yields a strong aluminum sulphate solution which is concentrated and crystallized to form commercial alum, and a washed silica residue which may be discarded virtually free from the valuable aluminum salt.

**Caustic Soda**—Soda ash solution, causticized with lime, yields a solution of caustic soda in which there is suspended precipitated calcium carbonate ( $CaCO_3$ ). C.C.D. treatment of this pulp yields a strong caustic soda solution and a washed calcium carbonate.

**Phosphoric Acid**—Phosphate rock, containing  $P_2O_5$ , digested with sulphuric acid, yields a solution of phosphoric acid in which there is suspended finely divided calcium sulphate ( $CaSO_4 \cdot 2H_2O$ ) precipitate. Both the acid and the synthetic gypsum being of value, continuous counter current decantation gives two products: first, a strong phosphoric acid and, second, a washed gypsum sludge suitable for the manufacture of building materials.

The following actual example is taken from an alum plant where C.C.D. replaced batch digestion of rock and washing of residue with savings of the following order:

Table II—C.C.D. vs. Batch Operation in Alum Plant

	C. C. D. Plant	Batch Plant	Annual Saving
Labor.....	1 man per shift	3 men per shift	\$7,776
Steam in reaction.....			5,760
Overall recovery, available $Al_2O_3$ .....	97.5%	90%	13,406
Temperature of finished liquor and saving on evaporator steam.....	90°C.	30°C.	6,660
Strength of finished liquor and saving on evaporator steam.....	35°Bé	30°Bé	9,000
Total			\$42,602

Data used in above comparison were as follows: (1) Capacity, 100 tons alum (17 per cent  $Al_2O_3$ ) per day. (2) Labor, 48 cents per hr. (3) Bauxite, 50 per cent available  $Al_2O_3$  at \$14.25 per ton. (4) Steam at 37 cents per 1,000 lb.

The data presented below are averaged from good plant operation and accordingly are representative of results secured in practice.

Table III—Averaged Results Obtained in Typical C.C.D. Operations

	Alum	Caustic Soda	Phosphoric Acid
New materials			
a. Solid.....	Bauxite ore	$Ca(OH)_2$	Phosphate rock
b. Liquid.....	50°Bé $H_2SO_4$	$Na_2CO_3$	50°Bé $H_2SO_4$
Extraction in agitators (Per cent)	98.5	91.5 causticity	97
Strength of finished solution (Deg. Bé)	35, hot	15.8, hot	30 (22% $P_2O_5$ )
Temperature of finished solution (Deg. C.)	90	74	80
Washing efficiency (Per cent)	99	99.3	99
Over-all recovery..	97.5% of available $Al_2O_3$	.....	96% of available $P_2O_5$

**Hydroseparation**—If, let us say, we feed a 20-ft. thickener, with a rated thickening capacity of 20 tons a day, at a rate of 40 tons a day, it is obvious, first, that all of the feed particles will not settle out as before and, second, that the portion of the feed solids carried off in a cloudy supernatant will be composed of the finest particles in the original feed. The practice of intelligently overloading a thickener so that it separates the feed particles roughly according to their size is known as "hydroseparation." In practice the mechanism for hydroseparation may and does not differ materially from that suitable for thickening. Furthermore, there is nothing a hydroseparator can do that a bowl classifier cannot do better.

As in the case of thickening, Stokes' law is interesting, but of limited practical application. Settling tests are used, various depths of supernatant being drawn off at various time intervals to simulate hydroseparator performance and to determine the conditions which will yield a size split at the desired mesh.

The hydroseparator operates the same regardless of whether the fine overflow or the coarser solids settling are the valuable product. For pigments, the fine material is to be saved and the coarse material is re-ground or disposed of. In other instances clay or fine impurities are to be washed to waste from a sandy product and here, of course, the underflow is what we are after.

**Scope and Limitations**—Among the many materials treated are water-floated whiting, barytes, red iron oxide pigment; lithopone, blanc fixe and titanium dioxide, and fine artificial abrasives. Sometimes, the hydro-

separator operates in closed circuit with a wet grinding mill, so that the relatively coarse underflow or sludge may be returned to the mill for further grinding until subdivided to the point where it overflows the hydroseparator as finished product.

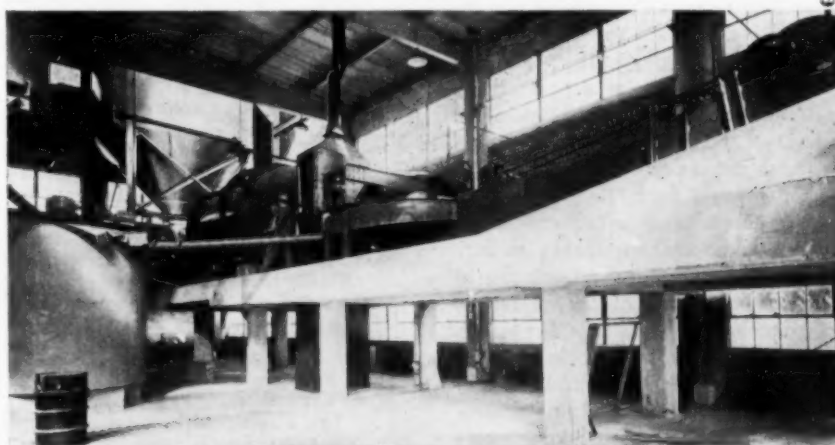
In hydroseparation, just as in thickening practice, operating results and conditions range far afield and data collected at one plant are worthless as an indication of results to be obtained elsewhere, unless scrutinized minutely and analyzed by one skilled in the art. Thickener capacities, it will be remembered, are usually compared on the basis of unit areas—sq. ft. settling area per ton 24 hrs. Hydroseparation capacities, on the other hand, are expressed as overflow rates, i.e., vertical upward displacement.

To produce a fine overflow product—98.6 per cent minus 325 mesh—on a water floated clay, a hydroseparator had to be provided to overflow a 26.1:1 pulp at the rate of 3 ft. per hour. Figured on a thickener basis, this was the equivalent of a unit area of 11.6 sq. ft. per ton per 24 hrs.

When later it became necessary to go to an even finer product—99.9 per cent through 325 mesh—the correct overflow dilution was found to be 41.5:1 and the correct overflow rate 1 ft. per hour. This figured out to the equivalent of a unit area of 56.1.

**Classification**—Classification and hydroseparation are somewhat similar operations but employ different machines. Both aim to separate a water-borne pulp into two constituents—a relatively fine overflow product and a relatively coarse discharge product. The fine overflow is material all but a per cent or two of which passes the (Please turn to page 283)

Fig. 4—Dorr bowl classifier in open circuit with rotary lime slaker, producing milk of lime free from grit



# Mechanical Concentration Methods

BY BYRON M. BIRD, chief concentration engineer of Battelle Memorial Institute, Columbus. Author of many papers on ore concentration and coal preparation, Mr. Bird was for ten years with the U. S. Bureau of Mines as supervising engineer of the Northwest and Southern Experiment Stations. His present connection dates from 1930.

CHEMICAL INDUSTRY has long recognized the value of certain mechanical operations, such as screening, thickening, filtering, and the like, but to a large extent it appears to have overlooked the possibilities of mechanical concentration methods, such as jigging, tabling, and launder processes. These processes, which have been developed to a high degree of efficiency in the metallurgical and mining industry, are applicable to a great variety of problems found in the chemical industry. They may be used in the beneficiation of raw materials to remove deleterious or inert portions, as in the removal of iron-bearing materials from glass sand; in the separation of spent materials in manufacturing processes, as in the removal of inert bone char from good char in the sugar industry; in cleaning up materials in the course of manufacture, as in the removal of particles of dirt from paper pulp; in the treatment of waste materials to recover valuable products, as in the recovery of fiber in waste water from paper mills; and in many other operations. Sometimes concentration processes can be used alone to effect the desired separation. More often they can be used advantageously as a preliminary step followed later by a chemical treatment, but in either role they hold many, as yet, unexplored possibilities for the process field.

In general, mechanical concentration methods are applicable to any case where there are differences in physical properties of the materials it is desired to separate. These differences may be in specific gravity, in size, in shape, in wettability, in magnetic properties, and in electrostatic properties. In many cases

advantage can be taken of several of these properties at one time in effecting a separation of a given material. Looked at from another standpoint, mechanical processes are particularly applicable to low-cost materials. Relative to the average chemical treatment, mechanical processes are very much cheaper; thus their use may well represent the difference between profit and loss.

Mechanical methods may be grouped into: (1) Those depending principally upon differences in specific gravity to effect a separation, such as tables, jigs, etc.; (2) those depending principally upon differences in surface properties, such as froth flotation; (3) those depending principally upon differences in other properties, such as magnetic or electrostatic properties.

The first of these groups, with which it is proposed to deal in this paper, may be further subdivided according to the primary method of separation, as follows:

## I. Wet Processes

### (A) Processes not using artificial media

#### 1. Vertical current processes

(a) Those using only upward currents: classifiers and some jigs

(b) Those using alternating upward and downward currents: most jigs

#### 2. Horizontal current processes

(a) Those without mechanical motion: most launders

(b) Those with mechanical motion: concentrating tables, mechanical classifiers

### (B) Processes using artificial media

1. Heavy liquid processes: calcium chloride, acetylene-tetrabromide

2. Those using suspensions: the Chance process, the Wuensch process

## II. Dry Processes

### (A) Processes not using artificial media

#### 1. Vertical current processes

(a) Those without mechanical motion: Stump table

(b) Those using mechanical motion: Sutton, Steele and Steele table

(B) Processes using artificial media: the Fraser and Yancey air-sand process

The groupings as given in this outline, although there is some overlapping between them, are valuable to an understanding of the distinctions between the processes. In this paper it is proposed to discuss these various processes, except the mechanical classifiers. The latter are primarily de-sliming devices rather than concentrating devices and will be treated elsewhere in this issue.

## Wet Processes

**Vertical Current**—The simplest form of vertical current device is the tube classifier, a vertical glass tube with a perforated plate in the bottom, through which is forced a continuous upward current of water. The materials to be classified are added in a batch, and the upward velocity of the water is so regulated that it is just sufficient to keep the coarsest particles in a state of suspension. If the materials are of one specific gravity and shape, they will arrange themselves in order of size with the coarsest at the bottom and a finer size at each higher stratum, while the colloids and extremely fine sizes will overflow. If the classifier set-up is such that the water is free from turbulence, the division into sizes will be exceedingly sharp in any given stratum, far beyond what it is usually possible to get with screens.

If some materials of the same size range but of higher specific gravity are now added to the teetering mass of solids in the classifier column, each of the new particles will seek its proper level in relation to a corres-

ponding size of lower specific gravity. The final arrangement in any given stratum will be such that the particles of low specific gravity will be larger than those of high specific gravity. If the experiment is further complicated by the addition of particles of a flaky or slabby nature but of the same size range, these new particles will tend to orient themselves so that their largest surface is at right angles to the upward current. As a result of the large surface exposed to the upward currents, a particle of any given specific gravity will be found higher in the sorting column than a cubical particle of the same specific gravity and weight.

This gives the stratification occurring in a hindered settling classifier. The so-called "classified products" from an apparatus of this type are obtained by dividing the sorting column into a number of portions, usually about six to eight, each of

which will show a gradation of sizes and specific gravities with the coarsest particles of lowest specific gravity, the finest of highest specific gravity, and intermediate sizes representing locked particles composed of both high and low specific-gravity materials. The slabby particles in each portion will have greater mass than the cubical particles of the same specific gravity.

The commercial forms of hindered settling classifier are legion, and so only two of the best-known types will be described—the Fahrenwald (commercially called a sizer), and the Hydrotator.

The Fahrenwald, sketched diagrammatically in part in Fig. 1, has a V-shaped tank ending in a cone (not shown) and surmounting a series of rectangular boxes with screen plates in the bottom, each of which receives a separate supply of upward-current water from a compartment beneath.

Uniform distribution of the water is obtained by control of the percentage of open area in the plate so that a slight pressure is developed in the compartment beneath it. This also reduces any tendency for boiling and eddying of the upward-current water. In the bottom of each classifying box and the dewatering cone are automatically controlled discharge spigots for the classified products caught in the several boxes as the

feed moves toward the right side.

The Hydrotator classifier shown in Fig. 2 is a simple tank with downward sprays mounted on radial arms, which in turn are supported by a vertical central shaft that is rotated. The water from the sprays is forced downward against the bottom of the tank and then flows upward. The amount of water is regulated to carry over materials of a given settling rate; materials of a higher settling rate are withdrawn from the bottom and discharged by means of a drag conveyor.

The distinction between the classifier and the jig, another type of vertical-current machine, lies mainly in the fact that the jig uses downward as well as upward currents. When pulsating downward currents alternate with upward currents, the range of sizes effectively separated is increased many times over that of a simple classifier. Theoretically, a separation is possible with the jig over practically an infinite size range if all sizes and specific gravities are present in the proper proportions. Actually no such raw material is ever encountered, and so in practice a jig operation is limited. Some idea of the possibilities of this process may be had from the fact that in what is probably the best all-round jig operation in this country the jig is handling a coal ranging from  $\frac{1}{8}$  to 5 in. in size at an average of 200 tons per hour.

As in the case of the classifiers, the makes and kinds of jigs are numerous, and so the discussion will be limited to the Baum jig, a machine extensively used in the cleaning of coal. A diagram suggesting the

Fig. 1—Diagram portraying principle of operation of a Fahrenwald sizer

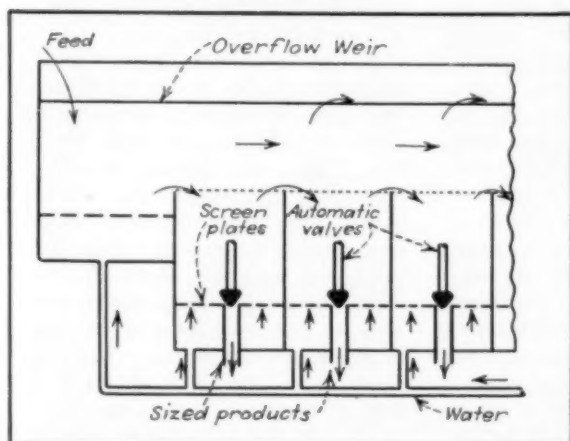


Fig. 2—Diagrammatic representation of Hydrotator rising current classifier

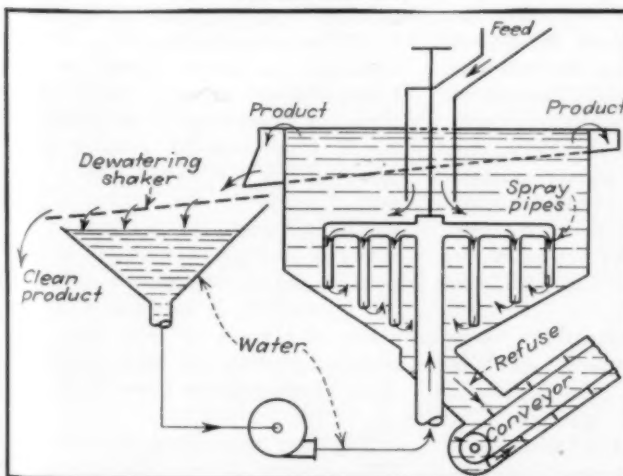
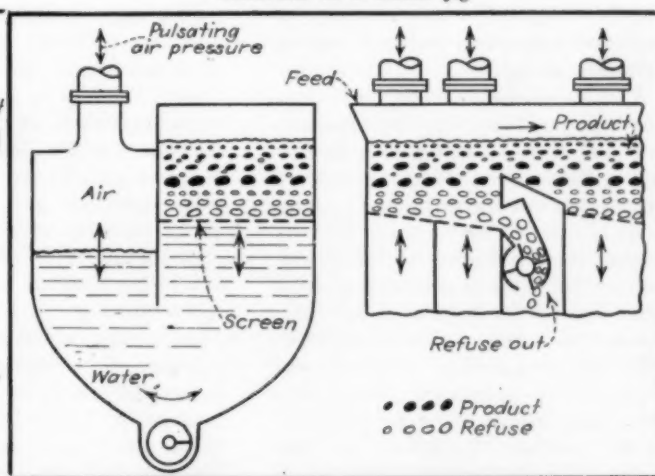


Fig. 3—Two simplified views showing segregation of materials in a Baum jig



operation of this machine is shown in Fig. 3. The raw materials are fed at the left and are subjected to upward and downward currents of water. The pulsations are produced by air admitted to the chambers provided along side the jigging compartments. (Some jigs use a reciprocating piston.) After the water has been forced up through the screen plate, the air is exhausted and the water and coal settle downward together, the coal being stopped by the screen plate while much of the water passes through, thus producing the so-called "suction" stroke. When the upward currents are adjusted to give mobility and the return strokes are regulated to give a gentle pull on the bed, the high-gravity materials—shale and bone—settle to the screen plate. Succeeding pulsations work them toward the right to the star refuse draws, by which they are withdrawn and dropped into the boot of an elevator. It in turn elevates them from the jig and dewater them. The cleaned coal flows over the weir at the right and is re-cleaned in a number of successive stages.

**Horizontal Current Methods**—The simplest form of horizontal current device is a trough inclined at a slight angle to the horizontal, so that the water will just transport all of the solids, coal, for example, without any deposition. Under these conditions the shale and bone, except the extreme fines, will be found in the bottom layers; the fines will be carried in suspension in the flowing currents. If a low gate be attached at the end of this simple launder, a bed of solids will form along the bottom. Let this end gate be gradually raised at just the correct rate and all of the refuse material from the moving mass will deposit on the bottom of the launder. However, if the raw coal is composed of mixed sizes, the deposited refuse materials will usually contain some coal.

A moment's consideration will show why this is true. In the ordinary raw coal there is a deficiency of certain sizes, and as a result there are spaces between the particles of refuse dragged along the bottom of the moving mass. These are filled with coal, and if there is a low spot in the fixed bed on the bottom of the launder and no refuse particles are available, the low-gravity particles will deposit. The tendency is for any coal deposited with the refuse to be on the average of smaller size than the high-gravity materials with which

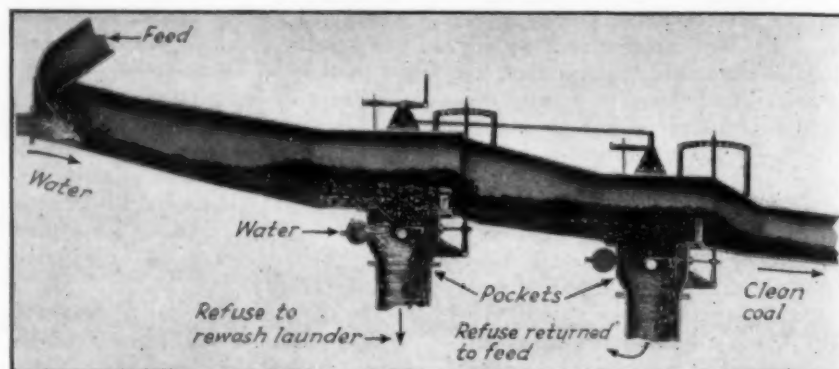


Fig. 4—Section portraying a single Rheolaveur coal cleaning launder in operation; additional cleaning stages are used in practice

it is deposited. Thus, it will be seen that the size-specific gravity relationship in the products of a flowing-current type of stratification is the reverse of that in a vertical current type; that is, *the highest gravity materials in a given product tend, on the average, to be coarser than the low-gravity materials.*

From this discussion it is evident that the horizontal current type of stratification requires some supplementary step to complete the separation of the particles according to specific gravity. To accomplish this, a great number of methods have been developed, which may be illustrated in the Rheolaveur process, a diagram of which is shown in Fig. 4. One aid to the separation is to build up large circulating loads of materials of intermediate and high specific gravities. This results in a relatively deep layer of refuse materials being spread over the bottom of the moving mass of particles. As a result, when a space exists in which a particle can be deposited, a refuse particle is available and it deposits in preference to a coal particle.

This same principle is further applied by re-treatment of the refuse products several times. On each subsequent treatment, the percentage of refuse materials is naturally higher than in the previous operation, and in consequence, the second or third refuse products are cleaner than the first. Upward currents of water are often introduced in the pockets to aid in the removal of fine coal from the refuse.

A launder which employs a large number of re-cleanings in specially designed pockets has been developed at Battelle Memorial Institute. The design tends to crowd the refuse particles and to prevent coal from de-

positing. Numerous upward currents of water are employed in the pockets.

Another attack on this problem of making a more complete horizontal current separation is to prepare a feed in which the particles have a specific gravity and size distribution such that they can be completely separated in flowing currents. As that method has been extensively used on the concentrating table, it will now be described.

A common type of table, diagrammed in Fig. 5, has a riffled surface and is reciprocated in a line approximately parallel with the riffles. The reciprocating motion is such that the deck moves relatively slowly away from the head motion, and quickly toward it. This transports the materials along the deck. Thus, the reciprocating motion serves both to aid mobility and to convey high-gravity materials. The feed flows on to the table at the upper left corner and across the moving deck. As the high-gravity materials are separated according to specific gravity and deposit between the riffles, they are transported toward the right. The low-gravity materials, as they flow across the riffles, are in effect given a large number of re-treatments and repeated washings by the water in the feed and by that introduced from suitably located water sprays along the upper side of the deck. However, the tendency previously discussed for the launder on a mixed feed (in which both size of particle and specific gravity influence the separation) is also found on the table, and more or less fine, low-gravity materials are found in a middling product at the lower right corner of the deck.

The best method of dealing with this problem on the table is proper

preparation of the feed. In the previous discussion, classification in upward currents of water was shown to yield products in which the low-gravity material is coarser than the high-gravity. If a classified feed is delivered to a flowing-current type of apparatus, conditions will be favorable for a sharp separation, for in the classified feed the high-gravity particles are all of fine size, and hence there are no interstices in the bottom layers in which the coarse low-gravity particles can collect. Thus, classification and tabling are complimentary processes, and the two together are highly efficient.

#### Wet Methods With Artificial Media

**Heavy Liquids**—As stated earlier, an ideal mixture of sizes and specific gravities can theoretically be completely separated in its own medium. However, such feeds are rare in practice, and since processes involving artificial media are to a large degree independent of the size-specific gravity relationships of particles comprising the materials to be separated, they enjoy an advantage, particularly where the differences in specific gravity between the particles being separated are small. Their use is, however, limited to cases where it is practicable to recover the medium.

Chemical solutions have been used extensively in a test method for coals and ores, the so-called "float-and-sink" method, and they have been used to a limited extent on commercial-scale operations. Of the true solutions, calcium chloride has been used most frequently. Acetylene-tetrabromide has also been used on a semi-commercial scale. In addition, there are in use several colloidal suspensions of clay in water. (The canning industry is at present making extensive use of salt brine in effecting a float-and-sink quality separation of such vegetables as peas. Recent work by the duPont company on heavy liquid processes using tetrabromethane (sp. gr. 2.964), penta-

chloroethane (1.678) and trichloroethylene (1.462), and their mixtures, has resulted in commercial application in coal beneficiation.—Editor.)

The apparatus for carrying out separations with heavy liquids consists of a tank with scrapers to drag the "float" from the top and other scrapers to remove the "sink" from the bottom of the tank. In addition to the tank itself, some means must be provided for removing the liquid from the particles being separated and some treatment for preparing it for re-use.

**Suspensions**—The best known of the suspension methods is the Chance sand-flotation process. Fundamentally, a Chance cone is a large hindered-settling classifier in which sand is held in suspension in upward currents of water and this sand-water suspension becomes the medium. Provision is made for stirring the medium to break up any turbulence that might otherwise develop. The float is removed from the top of the cone by the introduction near the surface of a large volume of medium, which simply washes the float from the top of the cone. The sink is withdrawn through a double gate arrangement in the bottom. The sand is removed from the coal and the refuse by screening and is re-injected into the cone.

#### Dry Processes

In the first group of dry separations, operating without artificial media, the energy supplied to keep the particles in a mobile condition comes entirely from vertical currents of air. There are a number of devices in this group, of which the one best known in this country is the Stump. This is fundamentally a classifier with pulsating upward currents of air. Materials flow from one end to the other with the high-gravity particles drawn off at the bottom, while the low-gravity materials overflow the end.

In the second group, the energy for maintaining the mass of particles in suspension is supplied by movement of the supporting deck as well as by means of vertical currents of air. One of the best known of this type of air table is the Sutton, Steele and Steele. Like the wet tables previously described, this air table has a riffled deck that is reciprocated in a horizontal direction roughly parallel with the riffles, but in the case of the air table the deck surface is covered with a screen or cloth and air from a

blower is forced upward through the mesh.

The only well-known dry process using an artificial medium is that invented by Fraser and Yancey. Basically, this method is the same as the Chance except that upward currents of air are used in place of upward currents of water to maintain sand in suspension and so produce a medium dense enough to float coal. The apparatus is a rectangular shallow box with a perforated bottom, through which the air current is forced. As in the Chance process, the coal is overflowed by the addition of a large volume of sand in circulation.

#### Applications to Raw Materials

Raw materials have such an important bearing upon the subsequent chemical processes and are in many instances so inadequately prepared at present that such a paper as this would be incomplete without some discussion of this phase.

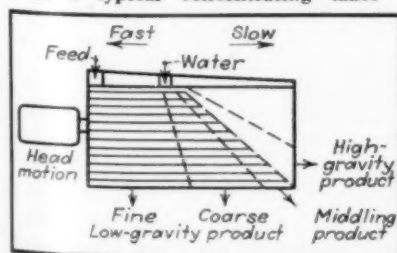
One well known application of concentration methods is in the beneficiation of phosphate rock, which not only improves the raw material but increases the recovery of phosphate. Froth flotation is the leading process, but classification and tabling have been used successfully. Another example is the concentration of fluorspar, some of which goes into the manufacture of hydrofluoric acid and into the enamel industry. Jigs, classifiers, and tables have long been used on fluorspar, and flotation is gradually being adopted. Both of these cases are fine examples of the benefits to be derived from concentrating chemical raw materials.

A ceramic material that has been receiving some attention in the past and is receiving more every day is glass sand. The problem is usually to remove iron oxide, and concentration methods are highly satisfactory for this purpose. In some cases, the mechanical treatment gives a sufficiently complete separation. In others, after coarse iron-bearing materials have been removed by tabling and similar methods, the sand must receive an acid treatment to clean the stain from the quartz particles.

A number of applications in the refractory industry have been suggested in a paper by Sullivan and Bird (Tech. Bull. No. 50, Am. Refract. Inst., 1934), from which the following is quoted:

"In refractory work ore-dressing methods may be considered for fireclays, high-  
(Please turn to page 284)

Fig. 5—Diagram illustrating action of a typical concentrating table



# Flotation Separation of Non-Metals

BY OLIVER C. RALSTON, chief engineer of the Non-Metals Division, U. S. Bureau of Mines, College Park, Md., who has been engaged in investigation—principally of flotation and hydro-metallurgical processes—for the Bureau of Mines since 1912. An extensive Bureau report on flotation will appear shortly under his signature.

CHEMICAL ENGINEERING now recognizes that in the method of separation by flotation it has a new and valuable tool, one which has been used for thirty years in the metallurgical field but which until relatively recent times has found few practical applications in other branches of chemical engineering. Froth flotation and its relatives, film or skin flotation and agglomerative or floccule separation from unflocculated materials by levitative methods, have come to be gradually adopted for separation, fractionation or purification of chemical raw materials, ceramic raw materials, mixtures of salts, coal, resins and natural hydrocarbons.

References covering all the adaptations of levitative separation would be too numerous to cite in this short article but will be found in an extensive review by the writer to be issued shortly as Bureau of Mines Report of Investigations 3397 under the title, "Flotation and Agglomerate Separation of Nonmetals." The purpose of the present article is to point out only the chemical engineering aspects of the method from the standpoint of its value as a new tool for chemical processing.

Whereas a mixture of elemental sulphur and rock would normally be separated by using solvents or by melting the sulphur and filtering, it might also be pulverized and the sulphur floated away by froth flotation, skin flotation or agglomerate tabling—all of which are levitative methods of separation. Or, the sulphur might

be melted under a solution of sufficiently high boiling point or under elevated pressure and the sulphur then levitated with air bubbles to pass into a froth on the top. The essential new aspect is to raft upward selected particles that normally are heavy enough to settle in the liquid used. If the particles do not normally attach themselves easily to a gas-liquid interface, filming agents or collectors are added in sufficient amounts to selectively film the desired surfaces so that they become lyophobic (repellent to liquid).

No two solids have identical surfaces, and anyone seeking a means of separating a mixture of the solids must first pulverize the mixture until substantially all the unlike particles are broken away from one another. Thereafter, a reagent must be added that will film only one solid selectively in such a manner that the filmed particles are lyophobic while the other particles are lyophilic. The filmed lyophobic particles tend to draw together into floccules, even in coarse sandy sizes, and the most common but of no means only method of separating these selectively flocculated particles is by froth flotation. The art of separation by flotation has produced men skillful in selectively filming surfaces and yet whose names and technique are almost unknown to the pure scientists in colloid or surface-chemistry. In fact, the art has kept ahead of science to such an extent that the pure scientist has been the humble camp follower, seeking to explain the phenomena discovered and used by the flotation engineer (applied scientist), and seldom has the pure scientist been able to make even

suggestions that could be made use of.

In levitative operations, polluted surfaces are the rule and must be further polluted or altered until the desired selective filming produces hydrophobic (water repellent) behavior on the surface of one or the other of the desired minerals. An ore which has lain underground for eons of time has had opportunity to contact many different solutions and gases and is far from being as clean as it looks—even in freshly broken surfaces. Cleavage planes are zones of weakness where probably at least some contaminants penetrated long ago. The flotation engineer must expect to be dealing with polluted surfaces which may be "activated" or "depressed" by the contaminants. Part of the choice of reagents to bring about selective filming involves an attempt to remove undesired surface material or to superpose activating or depressing agents before the hydrophobic agent is applied. One of the most important means of controlling selective filming has been found to be the ionic atmosphere in the ground ore pulp; hence the pH must be carefully watched and controlled. Just how the pH can function in assisting or preventing filming is another of the mysteries of colloid science. For some mineral separations, at least, a part of the mechanism of pH can be explained but in many cases its influence is still inscrutable.

Levitative separations have been worked out and are in practical use for purification and concentration of many of the following chemical raw materials: barite, gypsum, fluorite, chromite, limestone, magnesite, dolomite, phosphate rock and phosphate

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pebble, sulphur, ilmenite, rutile and mixtures of salt crystals. Minerals that contain calcium, magnesium or barium ions are easily filmed by the use of fatty acids or their salts, due to the formation of insoluble soap films that are water-repellent. "Soap flotation" is now widely used.

Ceramic raw materials such as clays, feldspars, quartz, talc, nephelite and spodumene can be beneficiated by levitative processes. Most of this group demand other filming agents wherein the active or filming ion is the cation. The substituted ammonium compounds and nitrogen bases are by far the best developed of this class of filmers, and in each instance they tend to film acidic minerals like quartz, feldspar, mica and other silicates. The more finely divided the material, the less hydrophobic should be the substituents in the ammonium compounds or the pyridinium complexes. Thus short chain amines are best for clays while long chain substituents are best for quartz.

Separations of salts are of interest to chemical engineers because in the past the separation of salt mixtures has involved, all too frequently, laborious evaporation and fractional crystallization. The separation of potassium chloride crystals from sodium chloride crystals in their saturated brine, as now practiced in both America and Russia, came as a distinct innovation. Whereas the natural mixed ores yield easily to filming of only the potassium

chloride by some of the sulphated aliphatic alcohol salts, the fatty acids will film sodium chloride selectively after "activation" with small amounts of lead chloride. Froth flotation with any convenient frother is, then, a simple matter, and by this means a separation which is far from being merely "rough" is effected. For fertilizer use the potassium chloride fraction is quite satisfactory. Certainly this all means economy. Other separations, such as borax or boric acid from other sodium salts or soda from ammonium chloride, have also been designed and are under intensive investigation. All that is necessary is that the crystal mush must contain separately crystallized materials, unattached to each other. Such mixtures have previously often been all too useless, but their separation by this means opens up new avenues leading to economy.

Chemical precipitates of small volume and slow settling rate can sometimes be removed from the bulk of liquid more expeditiously by prior frothing, only filtration of the froth then being necessary. The Thylox process of sulphur recovery from fuel gases involves scrubbing hydrogen sulphide from such gases with an alkaline liquid, then aerating the liquid in the presence of suitable catalysts to form elemental sulphur. The aerating gases bring the sulphur into a froth which can be separated easily. Powdered activated charcoal will col-

lect gold from dilute cyanide solutions and can be floated before filtration. In sugar purification with lime followed by carbonation the precipitate of calcium carbonate, together with colloidal materials, including proteins, can be froth-floated. In water purification, alum coagulation with the minimum of aluminum salt leads to long settling in retention basins. By addition of a suitable soap or fatty acid, aluminum soaps form which entangle the mud and permit its speedy froth flotation instead of slow settling.

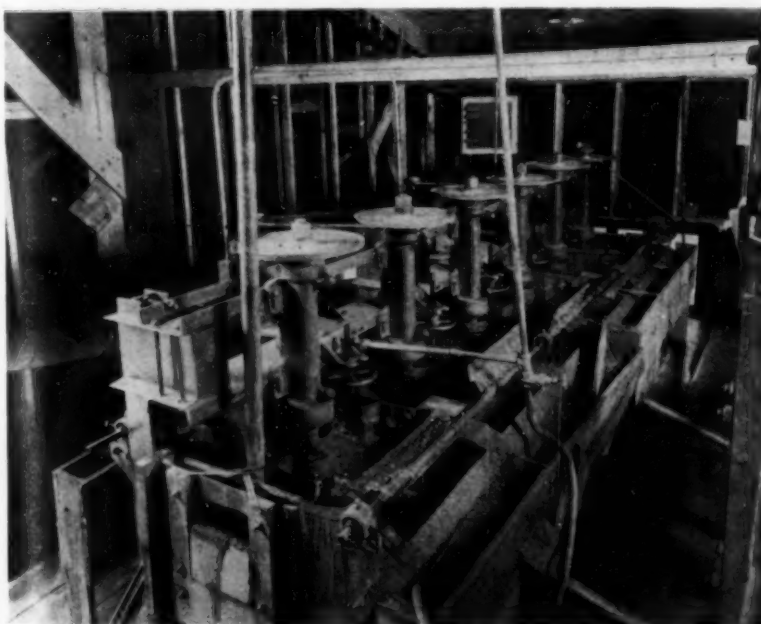
Materials in finely divided form are frequently lost in waste waters, due to difficulties in recovery. Paper pulp and fine coal are examples. Both are susceptible to froth flotation.

Bituminous coal is usually not a homogeneous substance but commonly carries bright and dull bands of coal that behave differently toward such processes as coking. Resins are also present in sufficiently large particles to be liberated during grinding of the coal to flotation size. The opportunities for separating fossil resins or of making coals of widely different coking characteristics, to be remixed in more desirable proportions or to be mixed with other coals, are great. For manufacturing special products such as electrodes, three plants in Europe are extracting from coal slurries a fraction with almost negligible ash content. Not all the constituents of coal are easily susceptible to hydro-

(Please turn to page 281)

Left—Six-cell Denver Sub-A mechanical flotation machine. Tailings from one cell feed to the one adjoining

Right—One of a bank of Fagergren flotation cells used for adjusting silica-calcite ratio in cement kiln feed



# Principles of Mineral Flotation

BY F. L. BOSQUI, metallurgical engineer at the Westport laboratories of The Dorr Co., Inc. He was formerly research engineer for Rhokana Corp. in Northern Rhodesia, where he developed an electrolytic and a flotation process for recovery of cobalt.

THE FIRST MENTION of an art employing flotation principles, according to D. J. Hoover, can be found in the writings of Herodotus some 2,000 years ago. The record states that gold dust was recovered from the mud of a certain lake by dipping in feathers smeared with pitch. Collecting minerals in such a fashion was destined, however, to become one of the lost arts and not to be rediscovered until the middle of the last century.

The first patent covering the use of oil for metallurgical purposes was issued to William Haynes in England in 1860. He mixed coal tar and resin with crushed ore and produced a sort of dough, from which the waste rock was removed by washing with water. The idea did not materialize into anything of a practical nature.

In 1885, Bradford, an American, obtained a patent for saving floating materials which were being lost in the ordinary gravity methods of ore separation. He noticed the "peculiar property" possessed by these particles of not becoming wetted.

Probably the first working plant to employ flotation was set up at the Glasdir Mine in Wales in 1898. A large quantity of a heavy oil residue was mixed with the ground ore, and fair recoveries of copper, gold and silver were made by separating the sulphides buoyed up by the oil.

It is curious that nobody in 1900 recognized the important part ultimately to be played by air in flotation. Although a number of small, more or less experimental, plants were built in different parts of the world to apply this bulk oil flotation process, no important advances were made until froth flotation began to be used.

The Potter-Delprat patents in 1903 show the earliest recognition of bubble levitation, and in that year a plant treating nearly 1,000 tons per day was put into commission at the Broken Hill Mines in Australia, using their method of generating gas in the pulp by means of acid. About this time an Italian, Fromont, found that air could be introduced into the pulp by means of rapidly moving stirrers, or propellers, thereby dispensing with gas generation, and his machines represent the earliest examples of the mechanical type of cell of today.

Still another method was invented by Elmore in 1904. This consisted in subjecting the ore pulp to a vacuum, which caused the air naturally dissolved in the water to precipitate or "condense" on the mineral particles and float them to the surface.

In the United States some experimental plants were run between the years 1900 and 1906, but little interest was shown in the flotation process until 1911, when a plant was erected at Butte, Montana, to treat lead-zinc ore. From then on progress was rapid in this country; but when one considers that today we use flotation more extensively than any other country, treating more than 60 million tons a year, it is remarkable that we were so much delayed in coming into the field.

In the period 1911 to 1920 a great deal of work was done along the lines of investigating new oils and other chemical reagents, and this era of research culminated in the great discovery of organic collectors by Perkins in 1921. At about the same time, alkaline circuits were introduced, and have become standard practice since. The selective flotation of sulphide minerals and the

flotation of oxidized and non-metallic minerals have been the principal advances since that time.

Flotation is one of a number of ore dressing processes that have for their object the concentration of certain minerals in an ore. Even in the richest ores the valuable minerals are highly diluted with waste rock. In the case of gold and silver ores and certain oxidized copper ores it is often possible to recover the valuable constituents directly by chemical solvents, but in the case of ores carrying non-metallic values—sulphides, for instance—the elimination of a large part of the waste is necessary before further processing can be economically undertaken.

In practice the flotation process consists of passing a suspension of the finely crushed ore in water through a series of flotation machines or "cells" where the combined effect of agitation and aeration in the presence of flotation reagents results in the separation of the floatable from the non-floatable minerals. The former, collecting in a froth at the surface of the pulp, are skimmed off as a "concentrate" while the latter are continuously rejected as a "tailing."

A misconception as to the mechanism of flotation frequently arises. The minerals themselves do not float; in fact, the separations made are independent of the specific gravities of the substances concerned. Minerals are floated because they become attached to air bubbles and are carried up with them as they rise to the surface.

The first essential in flotation is, therefore, the production of an adequate supply of reasonably stabilized bubbles throughout the ore pulp. Forcing or beating air into water will not produce bubbles of any stability.

They coalesce while rising to the surface and burst almost at once. This rupture is due to the tension which exists in the films constituting the bubble walls.

#### Frothing Agents

Certain substances, possessing what is known as heteropolar properties, are particularly effective reagents for reducing surface tension, and are known in the flotation art as frothers.

Polar compounds are those, such as the common salts, which ionize in solution, conduct electricity and are highly reactive. The non-polar compounds, such as the hydrocarbons, possess just the opposite properties. As their name implies, heteropolar compounds possess both polar and non-polar groups within the molecule.

Amyl alcohol,  $C_5H_{11}OH$ , is an example of a frothing agent, the  $C_5H_{11}$  group being the non-polar end and the OH group the polar end of the molecule. All effective frothers contain either a hydroxyl (OH), carbonyl (CO), nitrile (CN), carboxyl (COOH) or amine ( $NH_2$ ) group in the molecule, and as shown in Fig. 1, the molecule is oriented with these polar groups toward the water phase. Pine oil and cresylic acid are probably the best known frothers in flotation work.

The surface tension of a liquid

Fig. 1—Orientation of frothers

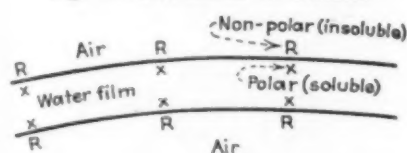
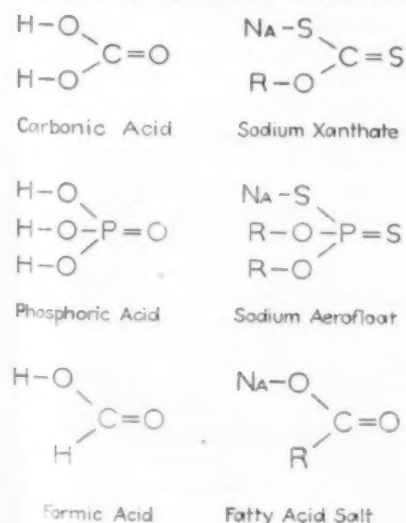


Fig. 2—Structural forms of collectors



can be measured by a simple mechanical device, but although we know it exists, there is no known method for measuring the surface tension of a solid. The degree of adhesion between liquid and solid determines its wettability. Conversely, the tendency of a gas to displace liquid from the mineral surface determines its floatability. These relationships are quantitatively expressed by the angle of contact of a drop of water on the solid surface, or a gas bubble adhering to the solid-liquid interface.

The separation of one mineral from another depends upon natural or artificially created differences in their surface characteristics. Depending upon whether a mineral surface possesses non-polar or polar properties it will "float" or "sink" under flotation conditions. In other words, the degree of non-wetting is a measure of its flotation behavior.

Those minerals which possess metallic, adamantine, or resinous luster (such as carbon, graphite, sulphur, pure metals) are naturally floatable. The sulphide minerals, in which form so many of the valuable metals occur in nature, also have a natural tendency to float, although this is largely influenced by oxidation and weathering action.

On the other hand, quartz and siliceous minerals generally tend to hydrate readily. A layer of hydrated silicic acid molecules forms a transitional layer between the solid and liquid phase, so that the mineral is "wetted" and sinks.

In a well agitated ore pulp containing a mixture of particles having polar and non-polar surfaces and through which a stream of fine bubbles is rising, the following action tends to take place as chance contacts between particles and bubbles occur:

(1) The gas phase displaces the water phase from non-polar surfaces and they cling to, and become a part of, the gas phase of the bubble.

(2) Conversely, the gas phase shows no tendency to displace water from polar surfaces and the bubbles and particles move freely and independently of one another.

Microscopic examination of mineralized bubbles shows them to be lined with a single layer of mineral particles. As regards size of bubble, there is as much objection to one too large as to one too small, and an average size of about 2 mm. does the best work. A high degree of dispersion consistent with satisfactory lifting

power of the bubbles is, of course, the aim.

The loaded bubbles rise to form a froth, which results from a draining away of the water between the bubbles as crowding increases. Some unwanted gangue material tends to be mechanically entrained between the bubble walls, but this can be reduced by refoaming. A good froth should have sufficient permanence to sustain its load of mineral, but must not be so gummy or tough as to hold up large amounts of gangue or be difficult to break down after leaving the flotation machine. The water content will vary from 60-80 per cent.

#### Collectors or Promoters

Like frothers, collectors have the characteristics of heteropolar compounds, but whereas frothers are concentrated at the gas-liquid interface, collectors are concentrated at the solid-liquid interface, and promote the attachment of the mineral to the air bubble.

The flotation mechanism as described using frothers alone is based on the assumption that the mineral surfaces have not undergone marked alteration of any kind. As a matter of fact, considerable alteration of mineral surfaces (even freshly broken surfaces) does take place during mining, milling, and storage, and gives rise to complications in flotation. Tarnishing due to thin films of oxides is the most common cause of failure of sulphides to float. The adsorption of slime material, which gives all the effect of a wetted surface, is another. Conversely, normally non-floating material such as quartz becomes activated by the adsorption of foreign ions, such as the ferric and cupric ions, and behaves like a non-wetting mineral. Collecting agents tend to overcome such adverse conditions and are universally used today for this reason and because their presence is essential to the highly selective work that must usually be accomplished.

As in the case of frothers, the two parts of the collector molecule have dissimilar functions: the polar part reacts chemically with the mineral surface, while the non-polar part, oriented outward from the mineral, promotes bubble attachment through its water-repelling properties.

Probably the most typical and widely used of the collectors are the xanthates (dithiocarbonates). They are produced by the reaction of carbon disulphide, an alkali base, and

an alcohol. Their structural form is important, and Fig. 2 shows how they consist of a substituted form of carbonic acid.

Complex compounds with useful collecting properties have been built up from the carbon nucleus type, especially where one of the sulphur or oxygen atoms has been replaced by nitrogen-hydrogen groups, but it is remarkable that in all these compounds we find at least the C=S (double-bonded sulphur group), and it is apparently this sulphur atom which is responsible for their chemical and physical behavior.

Another group widely used is the dithiophosphates or Aerofloats. These compounds are the reaction products of  $P_2S_5$  with alcohols or phenols and represent a substituted form of phosphoric acid and its salts. In this case the central atom is phosphorus instead of carbon.

Still another type of collector widely used for floating oxidized minerals and non-metallics is the fatty acid group. Structurally, these compounds are derived from the simple hydrocarbons by the substitution of a COOH (carboxyl) group for a hydrogen atom. The long-chain members of this series are good collectors, the best known being oleic acid. Stearic and palmitic acids are other members of this class, and since they all possess a carboxyl group, they are active frothers as well.

Within the last few years compounds known as cationic reagents, in which the hydrocarbon groups are in the positive ion of the molecule, are being experimented with, and interesting results are being obtained especially in the case of non-metallic minerals. One of the best known of these compounds is dimethyl cetyl ammonium bromide.

In addition to the frothers and collectors described, a number of other chemical reagents are used to control flotation behavior. These are listed below, with their principal function briefly noted, though it must be remembered that a single reagent may possess several properties, all of which may be operative at one time.

**Inhibitors:** Prevent flotation of undesirable minerals, such as finely dispersed secondary silicate minerals.

(a) Colloidal—certain glues, resins.

(b) Non-colloidal—organic compounds such as malic and gallic acid.

**Activators:** Assist the flotation of minerals naturally or artificially depressed.

Soluble reagents which convert the mineral surface to a form tending to

promote bubble attachment—e.g. copper sulphate, lead and mercury salts.

**De-activating Agents:** Counteract or prevent the activating effect of, say, Cu ions on zinc mineral, or Ca ions on quartz.

Cyanide, for instance, abstracts Cu ions from solution into complexes, and sodium silicate precipitates Ca ions from solution and reverses Ca adsorption.

**Depressors:** Prevent mineral from floating, permanently or temporarily, by chemical or physical reaction.

(a) Chemical—The action of potassium bichromate on lead minerals.

(b) Adsorption—The action of cyanide and lime on pyrites. Much difference of opinion here as to actual mechanism, but probably adsorption of OH ions wets the surface.

**pH Regulators:** Control degree of alkalinity, and in most cases affect dispersion of particles in suspension.

Alkaline circuits are generally preferred in flotation work today, because (1) there is less corrosion on parts, (2) soluble salts which depress minerals and consume collectors are thrown out of solution, (3) controlled dispersion along with other desirable effects only possible in alkaline pH, can be maintained.

Lime is most generally preferred but both soda ash and occasionally caustic soda find commercial use.

**Toxic Agents:** Prevent flotation due to adsorbed films.

Example: Aluminum and chromium

salts—action perhaps due to production of colloidal hydroxides by hydrolysis.

**Anti-toxic Agents:** Counteract above action, perhaps by the precipitation of flocculated hydroxides or basic salts that do not adsorb.

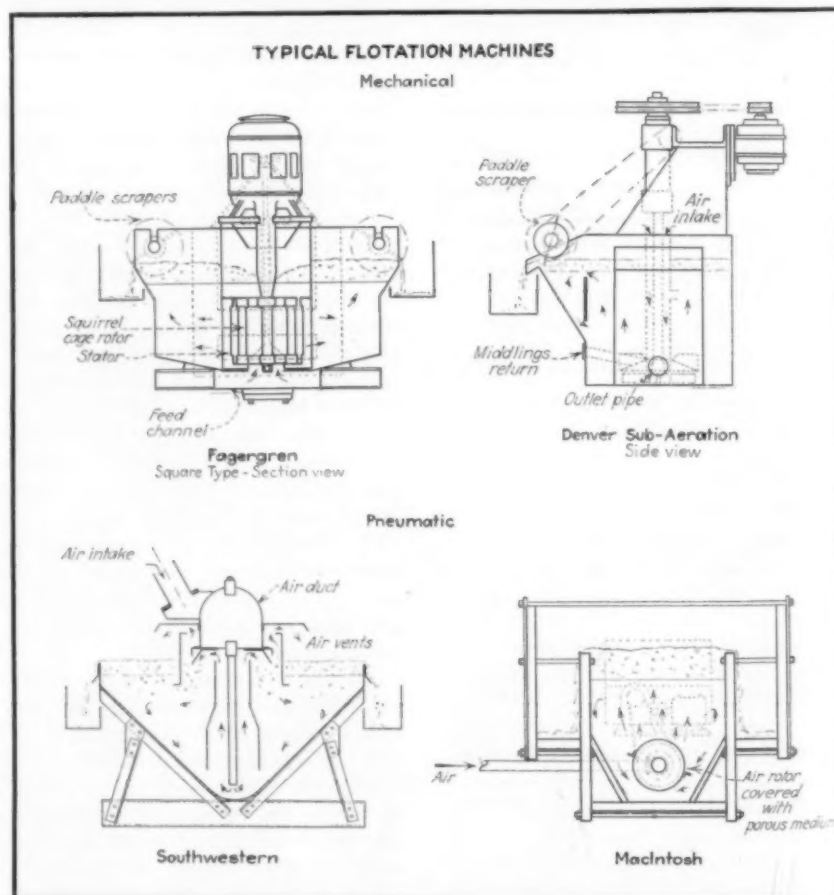
Somewhat dispersed pulps are in general to be preferred in flotation as they tend to yield higher recoveries and give better concentrate grades.

Pulp dilution is expressed either as per cent solids, or as a water solid ratio, i.e., 20 per cent solids equals 4:1 dilution. A high dilution seems to be more essential for flaky minerals, assists dispersion, and gives cleaner froth, but low dilution is more economical of reagents and requires less cell capacity. Thick pulps are better for roughing—they give good recoveries but poor grade; thin pulps are preferred for cleaning because less solids are to be found in the liquid which is entrained in the froth.

#### Flotation Machines

The machines, or cells, used in flotation work may be classed under two main headings: (1) mechanical machines, (2) pneumatic machines.

Fig. 3—Sketches illustrating principles of typical flotation machines



Schematic sketches of these types are shown in Fig. 3.

Mechanical machines may be further subdivided into (a) forced aeration type, (b) natural sub-aeration type. The Minerals Separation cell, with compressed air supplied below the impeller, is a machine of the first type, while the Denver Sub-A and Fagergren machines are examples of the second type, the air being drawn in by vortex action. The functions of the impeller is (1) to draw pulp into the cell, in which capacity it acts like a pump, (2) to mix air into the pulp in a finely dispersed condition, and (3) to produce the necessary agitation, not only to hold the solids in suspension but to promote contact with air bubbles.

Pneumatic machines are divided into (a) the low-pressure open-pipe type and (b) high pressure porous diaphragm type. The Forrester and Southwestern are cells of the first type working on the air-lift principle, while the original Callow cell and its later form, the MacIntosh machine, are examples of the porous diaphragm type. In the pneumatic cell the air must also provide the agitation that is the function of the impeller in the mechanical type.

In general, the mechanical machines, due to the finer and more highly diffused air bubbles, make better tailings on fine mineral pulps, and are used exclusively for non-metallic and oxidized ore flotation. The higher power costs are offset by lower reagent consumption as compared with the air cells.

For average size, readily floatable minerals the pneumatic cells make as good a tail (i. e., as good a recovery) at lower installation cost and very low repair and maintenance cost.

Mechanical cells are, however, more flexible and more perfectly controlled, each cell acting as an effective conditioner and mixer where stage addition of reagents is required. The level of each cell can be changed independently of any other, and simplified return and cleaner circuit can be used.

In the mechanical machines, cells range in size from 18 in. to 56 in. square and from 2 to 5 ft. deep to the overflow lip. The superstructure is proportioned accordingly.

The Southwestern type of pneumatic cell may have a cross-sectional pulp area of 10 sq. ft., and range in length from 6 ft. to 110 ft. The rotor pneumatic type is usually not

over 12 ft. long, but with center bearings has been built up to 20 ft. long.

Mechanical cells are grouped together to form banks consisting of anything up to 18 or 20 individual cells, and interconnected in such a way that the discharging pulp from one feeds into the next adjoining, so that the feed entering at one end of a bank passes through each cell in turn before discharging from the other end.

In the case of the pneumatic cell, the pulp simply flows in at one end of the long rectangular tank and out at the other. Pulp levels in both types of cells are controlled by weir-type overflows with removable top slats.

In any series or bank of mechanical cells it is always possible, by returning concentrates from one or several advanced sections, to combine roughing and cleaning operations in the single bank of cells. The action of the impellers draws the pulp into the cell and no pumps are required. In pneumatic installations, however, separate cells are required for cleaning purposes.

In the past, the tanks of most types of flotation machines were constructed of wood—usually tongue jointed, with side and end bracing of wood or steel held together with tie rods. The modern tendency is, however, toward all-steel construction, as being more durable and cheaper in the long run. Rigid steel superstructures carry the motors and vertical spindles or shafting to which the impellers are attached. A direct drive is used in some types, while in others units are driven singly or in pairs through a V-belt drive. The V-shaped tanks of pneumatic cells are sometimes built of sheet steel electrically welded in place.

The speeds of mechanical impellers vary from 250 to 450 r.p.m., depending on type and diameter, and each requires a motor with a capacity of 1-6 hp. The Southwestern type of air cell requires up to 100 cu. ft. of air per minute per foot run of cell at 1-1½ lb. pressure. While the MacIntosh cell uses less than one-third the above volume of air, the pressure required is somewhat greater.

#### Reagent Feeders

The quantities of reagents used in flotation work have to be accurately controlled. A slight excess of oil rapidly produces unmanageable froths,

while a deficiency in collector will result in mineral losses in the tailings.

For materials such as lime and finely divided dry salts it is possible to use slowly traveling belt feeders, timed with the rate of feed of pulp to the cells. But where it is possible to make up stable solutions mixing tanks are provided, and solutions of known strengths are fed to various types of solution feeders supplying the cells. The best known of these is probably the disk and cup feeder. The disk is driven at a constant speed by means of a reduction gear, and cups may be attached, or removed, or the degree of tilting altered, as more or less reagent is required.

Since each ore to a large extent represents an individual problem, it is generally necessary to carry out a laboratory program before an application of flotation can be made. Small batch machines are used for this purpose, together with small ball mills, permitting determination of such variables as degree of grind, kind and quantity of reagents, time of contact, and recovery, for use in the design of the full-scale plant.

#### Installation and Operating Costs

The cost of flotation equipment varies greatly. While a whole plant as designed to receive coarse ore may cost from \$350 to \$900 per ton of daily capacity, it is stated by Gaudin that the flotation division alone will average \$50 to \$100 for a one-concentrate circuit, and \$100 to \$175 per ton of daily capacity for a two-concentrate circuit.

Operating costs for a whole mill averaged in the U. S. (1926-1929) 67 cents per ton for 2,000-ton a day plants making one concentrate, and \$1.23 for 500-ton plants making two concentrates. Thus while the unit cost drops with increased scale of operation, it is increased by complexity of treatment. While crushing and grinding may account for 50 per cent of the total cost, the flotation division alone is not over 25 per cent of the total.

Total power consumption ranges from 12 to 20 kw.-hr. per ton for a one-concentrate plant to 20 to 40 kw.-hr. for a two-concentrate job. Of this, grinding and classifying account for 45 per cent and flotation itself about 30 per cent, either for mechanical drive or for blowers supplying the air in the case of pneumatic cells.

FOLLOWING in the next seven pages is a group of three articles dealing with electrical rather than mechanical separations

# Separation by Magnetic Methods

BY SAMUEL GIBSON FRANTZ, of S. G. Frantz Co., Engineers, New York City. For many years a consultant in the engineering, design and building of magnetic separators, Mr. Frantz now has his own company for the development and manufacture of this type of equipment. He is the inventor of the isodynamic and screen-type separators.

ALTHOUGH THE popular belief still prevails that a few minerals such as iron and magnetite are magnetic, and all other substances are non-magnetic, it was established nearly a hundred years ago by Faraday that no substance is indifferent to the magnetic field. By a series of experimental observations, this English scientist showed that any substance placed in a magnetic field will either increase or decrease to a varying extent the magnetic flux passing through that part of the field. It is this variation in the magnetic susceptibilities of different materials that makes possible the modern industrial methods of magnetic separation.

In principle, the magnetic separator is a machine which exerts a sufficient magnetic force on a mixture passing through it to deflect from its normal course that component having the greatest magnetic susceptibility. The forces involved in such a machine are of two types: (1) those which are proportional to mass, such as gravitational and magnetic forces, and (2) those which depend on surface, such as fluid friction and particle cohesion. In the case of dry materials, the particle cohesion forces are probably electrical in nature, and below about 150 mesh they become large enough, compared with the mass forces, to limit the possibilities of magnetic separation. In the case of wet separation, where fine particles are separated magnetically from a liquid stream, the viscous drag represented by fluid friction between the particle and the liquid is the main

force opposing the magnetic force.

To understand clearly how a magnetic separator works, it is necessary to consider the physical laws governing magnetic forces on particles. All engineers are familiar with the formula  $B = \mu H$ ,  $B$  being the flux density,  $H$  the field intensity, and  $\mu$  the permeability. Since there are only a few substances for which  $\mu$  is very different from unity, it is more convenient for comparative purposes to use the quantitative expression for susceptibility rather than permeability. The true, or volume, susceptibility,  $k_v$ , is related to  $\mu$  by the equation

$$\mu = 1 + 4 \pi K_v \quad (1)$$

and is defined as the ratio of the intensity of magnetization to the field intensity within the substance. The mass susceptibility,  $k$ , is the volume susceptibility divided by the density  $D$ . Measurements and tabulations of susceptibilities are usually in terms of  $k$  rather than  $k_v$ . The quantity  $k$  has never been found to be exactly zero, but its value is often very small in either the positive or negative direction. From the standpoint of magnetic separation, the following somewhat arbitrary classification of materials may be made:

Range	Mass Susceptibility, $k$ , in c.g.s. electromagnetic units
Very strongly magnetic	1 and over
Strongly magnetic	$10^{-3}$ to 1
Feebly magnetic	0 to $10^{-3}$
Diamagnetic	$-10^{-4}$ to 0

The mechanism of magnetic separation may be described as follows:

When a particle is placed in a magnetic field it becomes polarized, equal and opposite poles being developed at its ends. If the field is uniform this results in equal and opposite forces which may tend to orient the particle, but not to move it. If the field is non-uniform, however, the two forces will differ either in magnitude or direction, and they will have a finite resultant in the direction in which the field is increasing.

The mathematics involved in the above general description is rather involved, but it will suffice to say that for a spherical particle of volume  $v$  located in a magnetic field, the force exerted on the particle is

$$f = \frac{v k_v C}{1 + \frac{4}{3} \pi k_v} \quad (2)$$

where  $C$  is a vector which is proportional to the energy gradient of the field in the region of the particle.

In a separator the value of  $C$  generally varies greatly from point to point in the field. Near a magnetized edge it falls off inversely as the cube of the distance from the edge, and near a magnetized point inversely as the fourth power of the distance. In separators using edges, values of  $C$  for a point close to the edge may go as high as  $10^{10}$  c.g.s. electromagnetic units, while a millimeter or so away this may be reduced to  $10^7$  c.g.s. units.

Magnetic separation may be used under the most favorable conditions even on feebly magnetic and diamagnetic substances. The susceptibilities of many compounds have been measured and tabulated. See, for example,

the table in the "Handbook of Chemistry and Physics," 20th edition. Unfortunately no useful tables can be found for most of the materials actually encountered in separation problems. Natural materials in particular have susceptibilities which vary greatly according to their source and to small differences in impurities. The reader should guard especially against a "Table of Attractive Forces" which has been recopied, with accumulating errors, in various publications for 20 years or so.

The only sure way to find out if a separation is possible is to try it. As a rough guide, however, the following may be useful:

Very strongly magnetic elements whose compounds are likely to be strongly magnetic are Fe, Ni, Co.

Elements with high atomic susceptibilities whose compounds are likely to be magnetic enough to permit separation are Cr, Mn, V, W, Ta, Pt, and the group Ce, Dy, Er, Ho, Pr, Yb.

Most of the compounds of the other elements are diamagnetic in the pure state, but with proper equipment it has been found that some of them can be purified magnetically by taking advantage of their negative susceptibility. Most of the white minerals are diamagnetic.

#### Susceptibility Characteristics

Since the mass of a particle is  $m = vD$  grams, the magnetic force in dynes per gram is

$$\frac{f}{m} = \frac{1}{D} \left( \frac{k_v C}{1 - \frac{4}{3} \pi k_v} \right) \quad (4)$$

If  $k_v$  is very small, we may write (4) as

$$\frac{f}{m} = \frac{k_v}{D} C = k C \quad (5)$$

thus showing that for small susceptibilities the force is directly proportional to the susceptibility. In order to lift a feebly magnetic particle,  $kC$  must be at least equal to gravity. If, however,  $k_v$  is not very small, this is no longer true. In the extreme case where  $k_v$  is very large, equation (5) reduces to

$$\frac{f}{m} = \frac{3 C}{4 \pi D} \quad (6)$$

The force ratio is independent of  $k$  and the force per unit volume becomes

$$\frac{f}{v} = \frac{3}{4 \pi} C = 0.239 C \quad (7)$$

This is the maximum which is approached as  $k$  is increased, and it explains one of the reasons for the difficulty encountered in separating materials of high susceptibilities from one another. As an example, let us take one substance, say iron, in which  $k = 50$  and  $D = 7.8$  and another, perhaps an iron oxide mineral, in which  $k = 5$  and  $D = 5$ . The forces per unit volume, from (2), are both within 1 per cent of  $0.239 C$  dynes per c.c.



Fig. 2—Screen-type wet separator. The fluid feed passes up through a stack of magnetized screens in the bowl

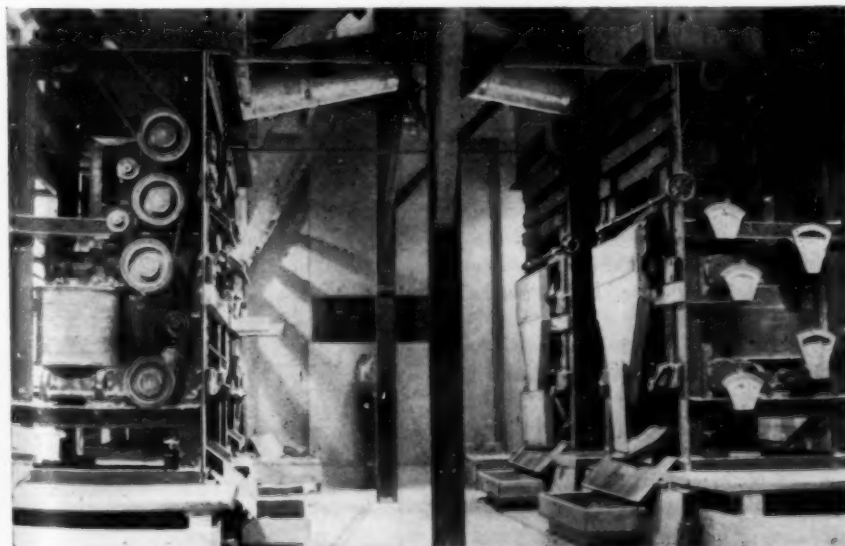
And since the magnetic forces per gram are practically inversely proportional to the densities of the two materials, we are faced with the apparent paradox that a higher value of  $C$  will be required to lift the iron against gravity than to lift the oxide!

Cases of this kind are met with only in dealing with very strongly magnetic particles; in most separation problems, equation (5) may be used. Note that the simplification of (5) over (4) comes from neglecting the second term in the denominator. If we trace the equation back to its origin we find that the "sphericity" of the particle is reflected in this term alone. It follows, then, that when (5) is substantially true, it is equally good for non-spherical particles. This also indicates that the less the susceptibility of a substance, the less will be the effect of particle shape on its separation.

#### Dry Separators

**Cross-Belt Type**—In this type of machine (Fig. 3) the dry granular mixture to be separated is carried on a horizontal conveyor belt which passes between the two poles of an electromagnet located respectively above and below the belt. The lower pole is flat and the upper one wedge-shaped with the sharp edge pointed down. This arrangement gives  $C$  an

Fig. 1—High-intensity induced-roll separators for removing iron from silica sand. The feed mixture enters at the top and as it falls over the induced rolls the magnetic particles are deflected from the stream



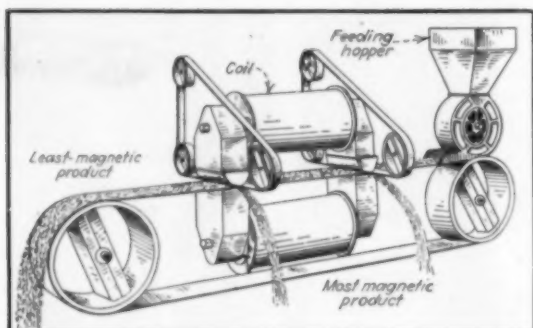


Fig. 3—Single-magnet cross-belt separator. For fractional separations, several magnets of increasing intensities are used in series

upward direction. Particles which have a large enough susceptibility to give a force per unit mass greater than gravity are lifted toward the upper pole. A horizontal cross-belt between this pole and the feed conveyor belt removes the magnetic particles as they rise up and drops them at one side. The lower limit of  $k$  for the magnetic fraction is probably about  $10^{-4}$ .

**Pulley Type**—This is simply a drum having poles on the periphery, magnetized by internal coils. The value of  $C$  is relatively low, and the machine is useful mainly for removal of tramp iron from granular material passed over its surface. One of its most common applications is in protecting grinding equipment.

**Roll Type (high intensity induction separator)**—In this machine (Figs. 1 and 4) a thin stream of properly dried and sized material is fed down a chute and over a long, narrow rotor. The rotor is highly magnetized by induction as a result of its location in the magnetic field between a primary pole of an electromagnet and a bridge bar opposite. Its surface is laminated in the form of alternate circumferential bands of iron and non-magnetic material so that there is a concentration of the magnetic lines of force upon the iron surfaces of the rotor. It is this concentration of flux which enables the field to act upon magnetic particles in the mixture stream and to pull them toward the rotor surface.

While the less susceptible particles in the feed travel over the rotor in their normal gravitational path, the more highly magnetic particles are deflected inward toward the rotor so that two separate streams are discharged. These are physically divided by an adjustable knife-edge splitter located just below the front of the rotor. The stream that is less de-

flected may be passed on over a series of rotors, each of which is progressively more highly magnetized than the last. The feed stream is split below each rotor, losing the particles that are sufficiently susceptible to be deflected by the stronger field encountered. Thus there is a magnetic fractionation of the original mixture and an end product is reached which contains substances that cannot or need not be separated

further by magnetic means. Sized feed is desirable, and the material must be fairly free-flowing.

This machine is capable of developing a greater value of  $C$  than the cross-belt separator, but it is not as satisfactory on materials which tend to stick to the rotors. Some separations being made by the roll type separator are: ilmenite-rutile-zircon; ilmenite-apatite; shale-borax; mica-feldspar; purification of silica sand; purification of abrasives; concentration of manganese ore.

**Isodynamic Separator**—In this separator, which has no moving parts, the value of  $C$  throughout the operating space is substantially a constant, while in all other types  $C$  varies tremendously from point to point. A stream of particles is allowed to fall freely through the space between two specially shaped pole pieces. The force is horizontal and deflects the more magnetic particles to one side. When the highest power is used, values of  $C$  can be obtained which are sufficient to give perceptible forces on diamagnetic particles in which  $k$  is as small as  $-0.2 \times 10^{-6}$ . In this way concentrations of diamagnetic minerals such as pure quartz, zircon, etc., can sometimes be made.

#### Wet Separators

When the particles of a mixture are too fine to be reasonably free-flowing dry separation is impossible; but when they are suspended in a liquid the cohesive forces are annulled, deflocculation being used if necessary.

Other than special-purpose machines used in concentrating iron ore, the principal types of wet separators are the trough and the screen types.

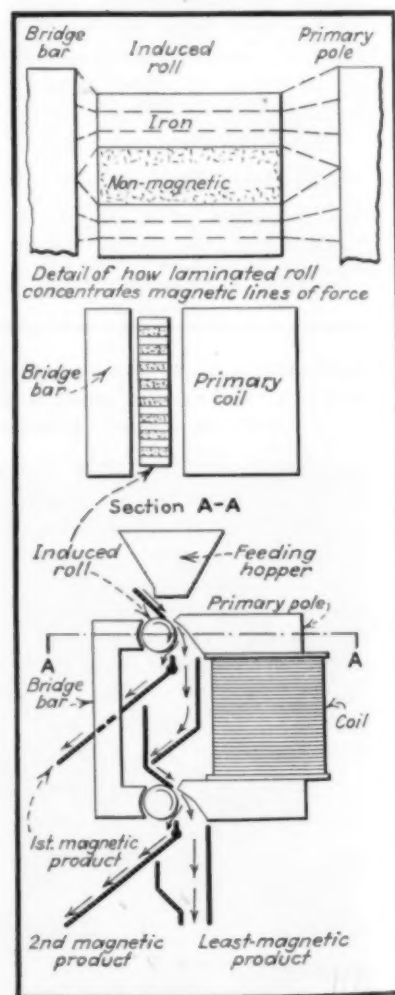
The trough-type magnetic separator consists of a slightly inclined trough having magnetized iron fingers or poles projecting from the bottom.

As the liquid passes through the trough, the magnetic particles accumulate on the poles. This type of machine, because of its low efficiency, is rapidly being displaced by the newer screen-type separators.

The screen-type separator (Fig. 2) consists essentially of a large number of magnetized screens placed one on top of the other and traversed in succession by the fluid. There are no moving parts. The screens present many feet of strongly magnetized edges so disposed that no particle in the liquid can escape repeatedly passing close to an edge. Near each edge the value of  $C$  is very high, and magnetic particles are pulled over against the viscous drag of the liquid, and held until released by demagnetizing the machine. Particles down to and below 1 micron are caught.

The first great success of screen-type (Please turn to page 285)

Fig. 4—Simplified diagram of roll-type high-intensity induction magnetic separator



# Electrostatic Solid Separations

BY HENRY M. SUTTON and G. W. JARMAN, JR., respectively vice-president of Sutton, Steele & Steele, of Dallas; and president of Separations Engineering Corp., New York. Mr. Sutton has given nearly 50 years to developing dry separation processes, while Mr. Jarman's interest in separations commenced in 1925.

CHEMICAL ENGINEERS have often found it necessary in the past to go into other fields for methods and machinery capable of bringing new accomplishments and new economies to the operation of their industries. Many of them have not realized, however, that there has been a renewal of interest in the electrostatic separation of solids from solids and that new methods have been developed, overcoming many of the disadvantages of the older electrostatic processes. Not a panacea for all separation ills, the new methods have nevertheless been found to be the most suitable ones in some applications. Already they have made an important place for themselves in such fields as seeds, spices, and the mineral industries. It is likely that they will prove equally useful in certain of the chemical engineering industries.

## Electrostatic or Electromagnetic?

Often those not familiar with methods of separation fail to differentiate clearly between electromagnetic and electrostatic processes. Both depend on forces which, although measurable, are not visible.

Electromagnetic separation is accomplished by placing a mixture of particles in a magnetic field which acts upon them in accordance with their varying magnetic susceptibilities. It is, of course, known that iron responds most freely to all magnetic attractions and hence in general the performance of a particle in a magnetic field depends somewhat on its iron content.

Electrostatic separation, on the other hand, depends on differences in the electrical conductivity or "suscep-

tibility" of particles, and this bears no relation to whether or not they are iron-bearing or magnetic. A good example of the process is shown in the separation of mustard seed from mouse dirt. This had been attempted by electromagnetic separation, by a separation in accordance with differences in specific gravity, and by rolling the mixture down a circular chute, hoping that differences in particle shape and rolling ability would achieve a separation. However, the only effective commercial method known is that of electrostatic separation due to appreciable differences in electrical susceptibility. No other method developed enough differences in the mixture to cause the constituents to respond sufficiently to the forces applied.

Electrostatic separation's history shows the usual patent interferences and litigation, some parts of which were solved by the expiration date of certain of the patents. It is of interest to note that one application was made in 1904 and issued in 1921. In general, the older types of electrostatic separators operated on the principle of putting one charge, either positive or negative, on to a chute and rotor over which were passed particles which were to be separated. This rotor was called a "separating" rotor and was charged from a high potential source of electricity. Rotated opposite this "separating" electrode was one termed "opposing," and this was charged with the opposite sign of electrical potential to that of the "separating" electrode. In this combination, it was absolutely necessary that there should be no free passage of electricity from one electrode to the other. To

prevent this, the opposing electrode was usually inclosed in an insulated tube of suitable material. This type of separator depended entirely upon repulsion of the various particles from the separating electrode. When a mass of particles, consisting of conductors and non-conductors, was fed to the separating electrode, the superior conductors received their repelling charge sooner than the non-conductors and were repelled over a dividing partition, while the non-conductors, requiring a longer time to receive a charge, reported behind it.

## Difficulties Encountered

One difficulty with this type of electrostatic separator was that there were many interferences between particle and particle in the falling stream. A particle which would normally be repelled might be underneath a particle which was not repelled and hence its arc of travel would not be sufficiently displaced from the vertical. On the other hand, a particle which was weakly repelled might be in a favorable position and hence land with those particles which were strongly repelled, rather than in an intermediate zone. Again, some particles which were strongly repelled never could get over the dividing knife edge on account of being unable to find their way through a group of non-repelled particles. This called for many passes in order to make a clean separation.

Another difficulty with this type was that small particles would stick to the opposing electrode, thus causing a partial convection of the charge at that particular point. Thus there would be spots on the separating elec-

trode in which repulsion of the desired particles was partly or wholly suppressed, making a more or less incomplete separation. It was found that any opposing stationary electrode of solid conducting material, whether surrounded with insulating material or not, was subject to this defect.

Research was conducted by Sutton and Steele, who were among the original patentees of electrostatic separation. They discovered that a gas tube electrode in which had been placed a conducting gas, such as neon, argon, helium, etc., is entirely free from the difficulty of small particles causing convection of the charge as above mentioned. This probably results from the fact that there is no solid conducting material within the gas tube to cause particles to adhere on the outside by localization of the charge at various points on its surface. Hence such an electrode cannot cause incomplete separation.

#### New Type of Separator

This led to the development of a new type of separator as shown in the accompanying sketch in which all particles were thoroughly charged by means of a convective static discharge until the non-conducting particles adhered to an electrically grounded rotor or "separating" electrode. This electrode was grounded so that the conducting particles, in losing their charge to the ground sooner than the non-conducting ones, fell off sooner and reported in front of a dividing knife edge, while the non-conducting ones reported behind it, since they took a longer time to lose the static charge which "pinned" them to the electrode.

It is clear that if a particle leaves the surface of a rotor at a point farther along in its periphery than another particle, it will fall in a path different than the one taken by another particle which leaves the rotor at a higher point. In the new separator particles of superior conductivity are assisted in losing their charge by the gas tube electrode which is somewhat closer to a horizontal plane through the rotor than the opposing electrode of the older type of separator first described. This gas tube electrode assists in the unpinning in a marked manner. If it were not present, some of the conducting particles might adhere to the separating electrode too long. The assistance is given by placing the gas tube electrode close to the point where the conducting particles would normally fall off

if there were no charge pinning them to the grounded rotor. Therefore, we have both the normal discharge of the conducting particles to the ground and the assistance given by rotating these particles into the electrostatic field of the gas tube.

It is evident that a combination of these two forces produces a remarkably efficient separation. Particles having the least polarization are attracted toward the gas tube electrode, while the polarization of the other particles is neutralized just sufficiently so that they become unloosened and fall behind a dividing partition, making a much more sharply divided stream of falling particles than was visible in prior types of static separators. Thus it can be seen that there is no interference of particles falling in the air and that only those particles which respond actively to the unpinning force can get over the knife edge. With the new method, which has been termed the "Electro-Float" type of electrostatic separator, the required number of passes has been greatly reduced.

Among various lines of investigation looking toward improved separation has been the etching of particles by acids and the deposition of foreign substances on the surface of particles to make them respond more readily to static charges. For example, the separation of feldspar from silica may be noted as being made possible in this manner. Another older instance is the coating of zinc blende with iron sulphide.

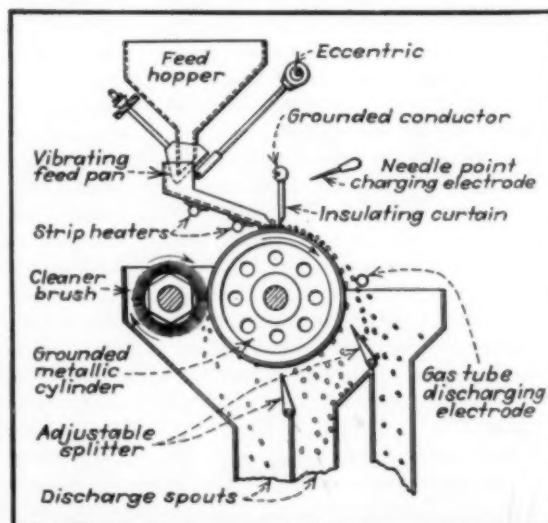
Another method using electrostatic separation which does not require supplying electricity is known as pyro-electric separation. This is achieved by first heating and then cooling a mixture of particles which are then passed down a chute made of material which will cause particles of opposite polarity to cling longer than those particles which have similar polarity to that of the chute. Mica and sand, for instance, poured down a glass chute after having been heated to a suitable temperature and then cooled the proper degree, will separate with the mica clinging to the glass and the sand fall-

ing off the edge of the lip. This unusual type of separation can only be accomplished in certain instances. Another example of a highly pyro-electric substance which can readily be separated from less pyro-electric substances by this method is tourmaline.

Static separations of the types discussed above are limited by the economy of the usual flow sheet, in that often it is cheaper to make separations in some other manner. However, where size separations are not feasible, where the particles will not respond to the strongest commercially available magnetic flux, and where their specific gravities are too close for one of the mechanical separations (as for example certain combinations of zircon and rutile) then it is generally possible to effect a clean separation by electrostatic force. The method has its limitations, such as the necessity for complete dryness and even the need for heating in certain cases. But where other, cheaper methods of separation, concentration or cleaning of raw and semi-finished materials have failed, this relatively unknown process offers a possible solution which it will be worth the chemical engineer's while to investigate.

(Editor's Note—A recent publication of interest concerning electrostatic separation is that of H. B. Johnson, presented as T. P. 877 at the February, 1938, meeting of the A.I.M.E. A tabulation of recent tests on 90 minerals lists separating voltages and whether or not minerals are selectively repelled.)

Diagram of new electrostatic separator showing method of charging and separating particles of different conductivities



# Modern Precipitator Practice

BY O. U. LAWRENCE, engineer in the Development and Technical Department of the Research Corp., Bound Brook, N. J., who for the past 15 years has been engaged in supervising the construction and installation of electrical precipitation equipment.

THERE IS A GREAT variety of equipment on the market for the recovery of suspended particles from gases. Each type of equipment is based on some underlying theory or law; hence it becomes the problem of the prospective purchaser of such equipment to determine what this underlying theory or law is, and, if possible, to define its limitations with respect to his particular problem. When fully informed on the nature of the problem to be solved and the performance characteristics of the available equipment, it is a relatively easy task to select the method which most nearly satisfies the requirements.

Electrical precipitation is one of several methods for the removal of suspended particles from gases, and it is carried out in four distinct steps, which may be enumerated as follows: (1) Charging of particles by means of gaseous ions or electrons, (2) transporting charged particles to the collecting electrode by the force of the electric field, (3) adhering of charged particles to the collecting electrode surface or to other particles previously deposited thereon and consequent discharging, and (4) removing precipitated material from the electrodes to suitable hoppers for subsequent disposal.

These steps can be carried out under a wide range of conditions and it is this fact which makes electrical precipitation useful in the process industries. Some of the characteristics of electrical precipitation which make this flexibility possible are the following:

1. The process is operative on suspended solid or liquid particles or a mixture of them in gases or vapors, or mixtures of the two.
2. There are no limits with regard to

the size of the solid or liquid particles which can be precipitated.

3. Percentage removal can be varied to suit economic requirements. It can be raised to a degree where engineering tests will hardly detect the presence of suspended particles.

4. No limitations are placed on the concentration or number of particles in the gases to be cleaned.

5. Operating temperatures may, under some conditions, be as high as 1,300 deg. F. Particles have been removed from gases at 125 lb. gage, but this is not necessarily the limiting pressure.

6. Equipment can take various forms to fit space limitations and means of tying into other equipment. Materials of construction can be selected to meet requirements of temperature, pressure and corrosion resistance.

7. Methods of removal of precipitated material can be varied to suit particular requirements.

Electrical precipitation first found application in problems already existing, in alleviating atmospheric pollution and in the recovery of losses or byproducts. Following the development of precipitation equipment for these purposes, engineers have become increasingly aware of its possibilities in more widespread use.

The method of utilizing the principles of electrical precipitation can perhaps best be illustrated by typical examples of specific applications. A number of such applications are given below, listed according to the field in which the installation is made.

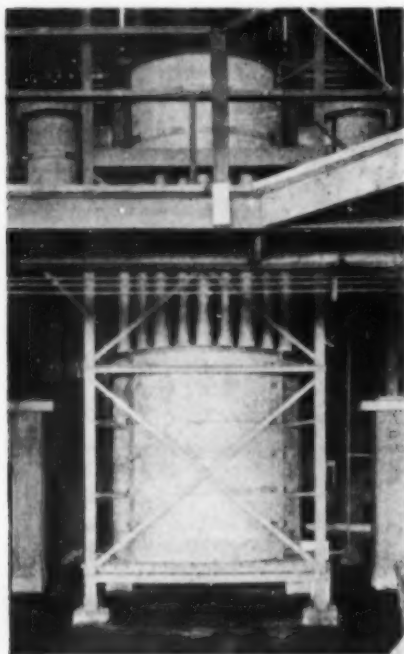
**Chamber Sulphuric Acid**—Gases evolved from the heat treatment of zinc concentrates in multiple hearth roasters require solids removal for subsequent utilization of sulphur dioxide for the manufacture of sulphuric acid by the chamber process. Sensible heat of the gases must be conserved for successful Glover tower operation. In order to carry out these objectives, the gases are

treated at temperatures from 900 to 1,200 deg. F. Usually, the solids content of the gases ranges from 3 to 6 grains per cu. ft. and recoveries of 95 to 98 per cent are required.

Precipitators for this purpose are built in two general types, arranged for horizontal or vertical flow, providing alternative methods for tying into existing flue systems. The precipitators consist of a number of parallel ducts arranged in square brick-lined steel shells. Wire discharge electrodes are hung along the centerline of each duct, while the walls of the duct serve as the collecting electrodes. Dust is deposited on the collecting electrodes and is periodically discharged into the hopper underneath by rapping. It is then removed by conveyors.

**Contact Sulphuric Acid**—In the contact process solids removal is effected in hot precipitators, after which the gases are cooled and other detrimental impurities, such as sulphuric acid, arsenic, etc., are removed as a second step. The precipitators employed for dust removal are similar in construction and operation to those used in the chamber process except that they operate at a lower temperature. For this reason discussion of the technique employed will be confined to the second step, that of liquid purification.

The second stage of cleaning is principally concerned with the removal of sulphuric acid mist, arsenic and other metallic compounds present in the solid phase. Requirements of the process are such that recoveries of the order of 99 to substantially 100 per cent are required. It is sometimes convenient to employ somewhat lower precipitator recoveries, but in such cases it is neces-



An electrical mist precipitator installed in a contact sulphuric acid plant which uses a platinum catalyst

sary to use auxiliary coke filters for the removal of final traces of acid.

These precipitators are constructed of corrosion resistant material supported from a steel structure, and usually consist of top and bottom headers connected by tubes which act as collecting electrodes. The tubes are usually partially submerged in the bottom header. Discharge electrodes are suspended in the tubes from a framework in the top header. Insulators supporting the discharge electrodes are protected by oil seals.

**Recovery of Waste Acid**—Great quantities of sulphuric acid are employed yearly in the processing of petroleum for the production of gasoline and allied products. After being utilized in this manner, the acid emerges from the process as dilute acid contaminated with elements which have been abstracted from the petroleum in the process of purification. Economic reasons, as well as restrictions against dumping, have made it desirable to reconcentrate this acid. This is usually accomplished by evaporating off the moisture and burning the combustible elements in the acid. In carrying this out, a certain amount of acid is volatilized which, if allowed to pass to the atmosphere, would constitute a nuisance as well as a considerable loss. It has, therefore, been the practice to recover this acid

by means of precipitators operating at sufficiently high temperatures so that the bulk of the water remains in the vapor phase and a reasonably high concentration of acid is obtained. Precipitators employed for this purpose follow conventional lines but are housed in acid-proof brick.

**Phosphoric Acid**—In the manufacture of phosphoric acid by either the electric furnace or blast furnace method, it is the practice to burn the phosphorus-bearing gases to produce phosphorus pentoxide which is subsequently hydrated. The resulting phosphoric acid mist is then recovered in precipitators operating at sufficiently high temperatures to produce the desired concentration.

Due to the corrosive nature of phosphoric acid, it is necessary to use uncommon materials of construction, such as carbon tubes and silver discharge electrode wires, etc. The value of phosphoric acid makes it worth while to get high recoveries which usually run over 99 per cent.

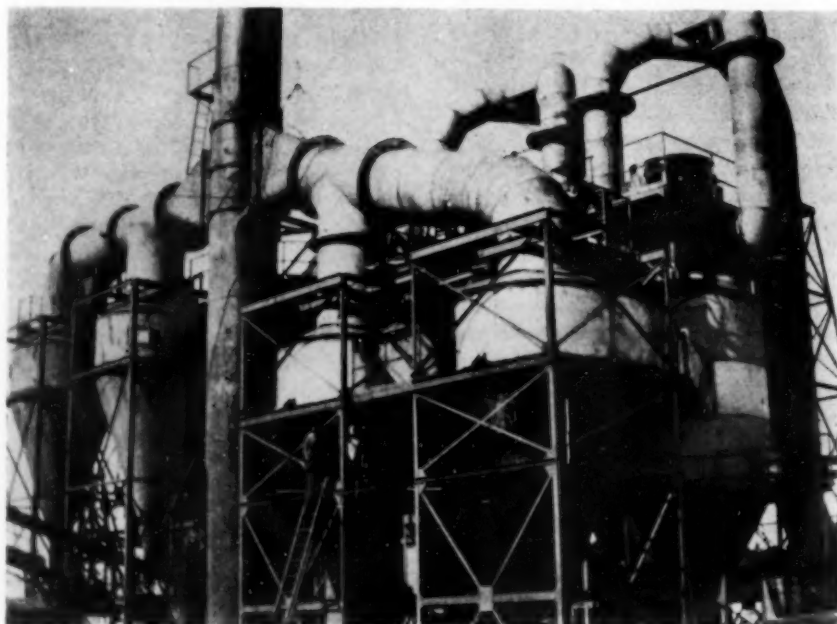
**Recovery in Pulp Mills**—Suspensions of soda compounds in finely divided form are found in the waste gases of soda and kraft pulp mills in sufficient amounts to make their recovery economical. By means of electrical precipitation they can be recovered either in solution or as a dry powder, depending on how the material can best be utilized.

**Carbon Black**—In the collection of manufactured carbon black, an

interesting modification of electrical precipitation has been found useful. Initial attempts to collect this material were along orthodox lines, but because of the extreme fluffiness and light weight of the precipitate, it could not be retained on the electrodes except at excessively low gas velocities which necessitated equipment which was too large and costly. However, it was found that the material which breaks away from the electrodes is composed of agglomerates which can be readily settled out in simple cyclones. Taking advantage of this fact a system was designed in which a relatively small electrical precipitator agglomerates the black for cyclone collection.

**Air Cleaning**—The more commonly used electrode arrangements in which charging and precipitation of suspended particles is carried on simultaneously, are liable to produce ozone and oxides of nitrogen in greater amounts than can be breathed without danger or discomfort and, hence, are not suitable for air cleaning. Since this results from the corona discharge which also charges the particles, separate electrode systems for charging and precipitation are used in air-cleaning precipitators. Thus it is possible to control the charging operation independently, reducing the charge to the minimum required for charging the particles. In this way, ozone is kept well below permissible limits.

Electrical precipitation in a carbon black plant is illustrated here by four units on a single stack. All cyclones and one of the precipitators are visible



# Gas-Solids Separation

*SEPARATION of solids from gases can be accomplished in a considerable variety of ways, most of which have been well described in recent literature. The following attempts only to outline the methods and mention certain sources of information.*

SOLIDS suspended in a gas stream are subject to three sorts of separation: Most often it is desired to remove the solids as completely as possible, or as may be needed, either to recover them, or to avoid a nuisance. Less frequently, although commonly in fine grinding, it is desired to separate the solids on the basis of particle size into coarse and fine fractions, and to separate both from the gas stream. Still less frequently, the aim is to produce a classification of the solids on the basis of specific gravity.

The recovery of solids from the gas is accomplished chiefly by five methods: by gravity settling; by inertial apparatus; by washers; by filters; and by electrical precipitators. All of these methods have been covered by Anderson in Perry's "Chemical Engineers' Handbook," Section 15, p. 1536; and more recently and more critically, by Miller in *Chem. & Met.*, Mar., 1938, p. 132. Miller lists a considerable number of useful references on most phases of the dust collection problem. Dust size classification theory has been treated briefly by Hardinage, *Chem. & Met.*, Dec., 1927, p. 737, while the theory of inertial dust collection equipment has been developed by Lissman, *Chem. & Met.*, Oct., 1930 p. 630. A preliminary report on the use of glass dust filter fabrics by Atkinson appeared in the Apr., 1938, issue of *Chem. & Met.*, p. 176. In the current issue, Bird describes classification of air-borne particles on the basis of specific gravity, while Lawrence summarizes the field for electrical precipitation of solids from gases.

Stokes Law, which is the theoretical basis of gravitational and inertial separations, shows that the settlement of particles depends on the (diameter)<sup>2</sup> and the specific gravity. Hence it is evident that these methods will classify according to both size and

density if particles of two densities are present. Inertial apparatus can be regarded as gravity apparatus in which the accelerating force is greatly increased by departure of the flow from a straight line. If sufficient time is provided for the settlement of the particles, or if the accelerating force is made sufficiently great, practically complete separation of solids and gas can be attained. Otherwise, a coarse and a fine size fraction will result, the latter suspended in the otherwise cleaned gas stream. Auxiliary cleaning means may then need to be employed, such as a filter or a washer.

Straight gravitational separation is found only in settling chambers, although the effect of gravity occasionally is found in one or two types of inertial equipment. Inertial devices include cyclones; multiple cyclones (Multiclones); baffle chambers; so-called cinder fans; dynamic dust precipitators (Rotoclones); devices in which separation is accomplished by impingement on wetted, oiled or viscous-coated surfaces; mechanical air separators (classifiers on size basis); vacuum and multivane separators used as integral parts of grinding equipment; and highly developed centrifugal collectors such as the Van Tongeren (Buell). In most of the devices the emphasis is on dust collection rather than classification.

Washers are built in a variety of designs, some of which may be described as mechanical and the others as non-mechanical. The mechanical types, of which the Feld scrubber, the Theisen Disintegrator and the water-sprayed type of Rotoclone are typical, all employ mechanical devices to effect violent contact between liquid and dust particles. A number of non-mechanical types, represented by the Freyn and the Schneible scrubbers, produce the desired contact by control of the velocity and motion of the gas with

respect to the flow of the washing liquid. Another mechanical type, the Bartlett & Snow, bubbles the gas through water on the surface of which is a floating layer of oil-stabilized froth. Spray washers, as used in air conditioning, represent still another type of washer.

Filters, which accomplish the finest separations aside from the electrical precipitators, may be classified according to whether the filter fabric is self-supporting, as in the bag types, or whether a grid support is employed as in the panel filters. Generally a shake-down means is provided. Until recently, cotton, wool and asbestos cloth were the principal media available. Work at present being conducted aims at making the new glass textiles available for applications where high temperatures or corrosive conditions are met.

## FLOTATION OF NON-METALS

*(Continued from page 269)*

generation, especially the so-called mineral charcoal, i. e., fusain or mother-of-coal. Concentration of only the easily hydrogenated fractions that are very low in ash will probably be one of the early commercial steps in the hydrogenation of coal.

This mention of separating a coking coal into fractions which can be recombined into mixtures of better coking behavior is only typical of other similar methods of beneficiating mineral mixtures by this combination of analytical and synthetic processes. Cement rock rarely has the calcareous and argillaceous constituents in ideal proportion. By fractionating roughly by flotation or agglomeration, followed by recombination into the exact desired proportions for each grade of cement that may be wanted, an element of inexpensive control is added which was previously lacking. Fractionating clays into ceramically different parts, followed by proportioned mixing in order to gain control over shrinkage, vitrification range or what-not, is another fruitful field now known to be possible.

Enough has been said in this thumbnail sketch to be provocative—not exhaustive. Wide vistas have been viewed but not entered, and the paper ends where it started. The chemical engineer is asked to become more aware of his new tool and to participate in the further extension of its sphere of usefulness.

## GRINDING FUNDAMENTALS

(Continued from page 229)

serve to give preliminary information and in some cases rather striking agreement with the flow rates determined by laboratory testing has been obtained in operating units. For any given problem there is an optimum flow rate beyond which there appears to be no great gain in ultimate capacity of finished material. This is undoubtedly greater with softer materials than it is with those that are more resistant, and it is an interesting fact that the optimum flow rate may radically change when finishing the same material at different meshes or at different amounts of new surface. This phase of grinding is now undergoing revolutionary changes, particularly in wet grinding, and the classifier manufacturers are to be praised for the marked progress which has thus far been attained in the art.

In the case of dry grinding the problem is not quite so simple because the means available for the control of finished product do not make it possible to delineate the sizing as closely as when wet separations are used. The problem is further complicated in dry grinding since it is not possible to secure flow rates of the same magnitude as those obtained in wet grinding.

The flow rate may be controlled by the use of classifiers, screens and air separators. In some cases the rate can be somewhat modified by air-sweeping the unit. This is not always effective, as there may be a tendency for the air currents to sweep only the surface which may result in a steady accumulation of extremely resistant material to be ground.

Using screens and wet classifiers often permits greater flow rates than can be obtained with the other devices mentioned. However, the use of screens is limited by the blinding effect of particular sizes and shapes of material in the screen fabric. Therefore, it is essential when producing fine sizes in dry grinding to use air separators, or else to operate in open circuit, or on a batch basis. The flow rate is affected by mill speed, size of grinding media, and by the size distribution of the material fed to the unit. In some cases it is necessary to add fine sizes to the feed in dry grinding to produce enough mobility in the charge to secure sufficient flow rate.

**Type of Circuit**—There are various types of grinding circuit used which may be designated as batch, open circuit, closed circuit, and combinations of open and closed circuit, where more than one stage is used. Batch grinding is often used in the process industries, being adaptable for limited tonnages, and for those cases where volatile liquids are used or other special conditions preclude the employment of open- or closed-circuit operation.

Open-circuit operations have their place particularly where simplicity of layout may be a determining factor, or where the product to be ground is not handled readily in separating devices. However, the most efficient type of grinding from the standpoint of power consumption and reduction to a given mesh size is the closed circuit, which involves the continuous withdrawal of finished and unfinished material and the return of oversize. Finished material is thus removed from the circuit or passed on to a succeeding grinding stage.

The number of stages to be used is dictated by the economics of the problem under consideration. In general, it is recognized that there are advantages, including an overall power saving, in using more than one stage, primarily because it is not feasible to provide a single grinding unit with the best selection of ball sizes and mill speed for the entire range of particle sizes handled.

## General Considerations

Sometimes corrosion of machine parts, or contamination of product dictates the choice of mill and grinding media materials. Where contamination is serious it may even be necessary to grind the material with larger pieces of the same material. This, in general, is not economical, but sometimes necessary. Danish pebbles and porcelain balls have been used successfully, as well as special alloys. Rubber covered rods and balls have been employed with and without lead or iron centers to increase their weight. Special liners made of porcelain, silex, rubber and alloy steel are sometimes utilized.

In general, when wet grinding can be used it is preferable because of the elimination of dust, and because it is in most cases more efficient in the use of power. In dry grinding consideration must be given to the coating of grinding

media and to the cushioning effect of the material to be ground. Coating of balls or liners may be serious and in some cases resists all efforts to prevent its formation. In general, cushioning can be controlled by providing means in the grinding unit for the rapid removal of contents. It is recognized particularly in cylindrical grinding vessels that discharge of the contents near the periphery or by some special means may be particularly advantageous. This does not apply to all problems, but it is obvious that the unit should be designed to prevent the accumulation of finished material.

Certain of the factors concerned in the selection of grinding equipment have already been discussed. For example, the type of disintegration desired is a primary consideration. More than one type of mill will usually be able to give the desired grouping of particle sizes, or the mesh size, unlocking or specific surface needed so that choice will usually depend on economic and operating factors. In the absence of identical operating information from similar plants, it is necessary to test the material carefully under controlled conditions. However, it must be emphasized that there are wide differences in the constitution of materials which are superficially similar, a fact which is best illustrated by reference to tabulations of comparative grinding resistances of different materials. (See, for example, *Grindability and Grinding Characteristics of Ores*, by F. C. Bond and W. L. Maxson, T. P. No. 388, A.I.M.E., 1938.) Even a casual scrutiny of such data will make it clear why it is necessary to have great variations in the size of units for grinding the same tonnages, and why careful tests are needed if optimum results are to be attained in a grinding installation.

Efficiency of grinding units is always an economic question, but the factor to be emphasized will vary with the particular conditions. In some cases the requirements of the product may warrant an operation that is far from economical, while in others, cost efficiency as reflected in low power consumption, long life and low wear may be of paramount importance. Still again, maximum capacity may be the criterion. These and the factors considered in preceding sections must be given their due weight if a satisfactory installation is to be achieved.

## SETTLING SEPARATIONS

(Continued from page 263)

mesh of separation; coarse discharge is the material, most but not all of which remains on the limiting mesh.

Reduced to its simplest form, a Dorr classifier consists of an inclined, rectangular settling box, with the upper end open, in which are placed mechanically-operated reciprocating rakes which carry the quick-settling coarse material to the point of discharge at the upper end. Each rake is carried by two hangers, one at the overflow and the other at the discharge end and is actuated by a head motion of cranks and linkages.

The Dorr bowl classifier consists essentially of a straight Dorr classifier upon the lower end of which there is superimposed a shallow circular bowl with a revolving raking mechanism. Feed enters through a central loading well; overflow takes place across a peripheral weir and coarse solids are raked to an opening in the center of the bowl and pass thence into the reciprocating rake compartment below.

Mechanical classification is employed in the process industries for three major operations: (1) making a size separation of the particles contained in a water borne pulp; (2) closing the grinding circuit to assure uniform fineness of finished material; and (3) washing a granular product, either to remove low grade fines or soluble chemical salts. It is limited, of course, to wet processing operations and is hardly applicable to size separations at meshes coarser than 6 to 8 mesh.

**Adjustments and Capacities**—All other factors remaining the same, the mesh at which the separation is made is determined by the speed of the rakes, the dilution of the overflow and the slope of the tank bottom. Broadly, the greater the rake speed, the lower the dilution and the steeper the slope the coarser is the separation and vice versa. Take quartz, 2.7 sp. gr. as an example. A 20 mesh separation corresponds to a rake speed of 27-32 strokes per minute, a dilution of about 1.5 to 1 and a tank slope of  $3\frac{1}{2}$ -4 in. per foot. If a 100 mesh separation were desired, the rake speed should be 16-20 strokes per minute, the dilution 4-6 to 1 and the tank slope  $2\frac{3}{4}$  to  $2\frac{1}{4}$  in. per ft.

All factors, including speed, dilution, slope, separation and materials remaining the same, the overflow and

the raking capacity are proportional to the classifier width. The finer the separation, the finer is the material raked and the slower must be the rake speed, both of which have the effect of reducing capacity. In the case of the 2.7 sp. gr. quartz and a 100 mesh separation, a light duty 3 ft. Dorr classifier might have a raking capacity of about 400 tons per day. At a 20 mesh separation, the same classifier should rake close to 750 tons per day. Heavy duty Dorr classifiers, with deeper rakes and longer strokes will obviously handle greater tonnages per unit of width.

**Size Separations**—In making whitening, fine water floated chalk, a bowl classifier is placed directly after the wet grinding equipment. The fine overflow goes to thickeners, then filters and finally to dryers, while the discharge is recirculated through the grinding unit until reduced to the desired point.

At one plant the bowl classifier is fed at 6.1:1 dilution and overflows at 10.1:1 dilution. At another the feed is 12.6:1 and the overflow 16.7:1. Yet both produce substantially the same quality of finished product—97.5 per cent through 325 mesh in the first case and 95.9 per cent in the second. The difference lies, probably, in the nature of the raw material, the character and temperature of the process water and many other apparently minor factors that are only detected by the trained observer.

**Closed Circuit Grinding**—Finished lithopone is generally wet ground and passed through a hydroseparator. Then the overflow is thickened, filtered and dried while the discharge is returned to the mill for further grinding. At one plant the dilution of the tube mill feed was 1.5:1, and dilution of hydroseparator overflow, 20:1. Feed to the hydroseparator ran about 2.6 per cent plus 325 mesh and the final product overflowing the hydroseparator, 0.25 per cent plus 325 mesh.

Table IV—Particle Size Analysis of Abrasives Ground in Closed Circuit by a Ball Mill With a Bowl Classifier

Size Range, mm.	Approximate Size Analysis (Per Cent)		
	Feed	Overflow	Discharge
+0.06.....	25	3	80
0.06-0.05.....	35	47	20
0.05-0.025.....	20	30	..
0.025-0.005.....	10	15	..
-0.005.....	10	5	..
Per cent solids.....	41.5	6.9	70.0

**Degritting Milk of Lime**—Lime slaking and the preparation of a smooth, grit-free milk of lime is a common step in the chemical process industries. Here

bowl classifiers are extensively used for removing grit, sand and unburned core from the slaked product so that the finished milk of lime may enter the next stage of processing devoid of such mineral impurities.

In general the final milk of lime must contain not more than a few per cent of plus 325 mesh material. But just how much plus 325 mesh can be tolerated has a tremendous effect on the unit area provided in the bowl. The law of diminishing returns comes into play with a vengeance and the unit area rises at a logarithmic rate when the last few fractions of a per cent must be removed. The table below shows this relation dramatically in the case of one lime tested.

Table V—Relation of Bowl Classifier Unit Area to Finished Fineness of Milk of Lime

Unit Area	Bowl Overflow (Per cent Through 325 Mesh)
5.3	96.3
15.8	98.3
18.3	99.3
20.6	99.4
35.6	99.8

To thicken this finest milk of lime a unit area of 114.3 was needed. This unit area was that determined by the slowest zone of the settling test—dilution 17.5:1. The final density of discharge was 3.9:1.

Milk of lime unit areas are subject to wide variations due to the physical nature of the raw materials and the conditions prevailing during slaking. The three cases tabulated below are typical.

Table VI—Some Unit Thickening Areas For Milk of Lime

Unit Area	Per Cent Through 325 Mesh	Final Density
114.3	99.80	3.9:1
64.8	..	2.2:1
50.2	99.98	2.86:1
142.0	99.73	.....

In preparing milk of lime for continuous causticizing, either at alkali plants or chemical pulp mills, a slaking technique has been developed for controlling the particle size and particle structure. Weak soda ash liquor is used in the slaker and dilution, temperature, time of contact and degree of agitation are held at the optimum points. A 75-80 per cent reduction in unit area has been obtained in this way and the principles employed are applicable to many materials other than milk of lime and lime mud.

Cases such as these could be cited indefinitely, illustrating the reactions of various materials to thickening, hydroseparation and classification treatment. The three unit operations discussed—thickening, hydroseparation and classification—are allied operations and fundamentally the same. They obey the same natural laws, employ similar machines, yet operate under slightly different conditions. Likewise, they have stood well the test of time and their use is virtually standard in many branches of the process industries.

## MECHANICAL CONCENTRATION

(Continued from page 267)

alumina clays, diaspores and bauxites, magnesites, chromites, olivines, kyanites, and silicas. The less common refractory materials such as zirconia, zircon, thoria, ceria, and the refractory aluminum silicates may also be amenable.

"The most common impurities of clays are quartz and feldspar, although mica, iron oxide, pyrite, gypsum, rutile, ilmenite, dolomite, and other materials may be present in appreciable amounts. Like impurities may be found in bauxites, diaspores, and similar high-alumina materials. Magnesites are nearly always associated with silica which may be present in the form of serpentine, quartz, chalcedony, opal, or other forms. Iron carbonate is present in most magnesites, probably as an isomorphous solid solution. Chrome ore is composed of chromite grains surrounded by silicate impurities. It is generally considered as an isomorphous mixture of various minerals of the spinel group in varying proportions in which part of the ferrous oxide may be replaced by magnesia, and part of the chromic oxide by alumina and ferric oxide."

Some examples not so well known may also be mentioned. One is the application of concentration to the treatment of pyrite from coal mines to remove excess carbon and inert materials before its use in the manufacture of sulphuric acid. For the concentration, jigs have generally been used, but classifiers and tables or launder processes should be satisfactory. In this case, the concentration process effects a saving in the cost of operation of the sulphuric acid plant. A second is the concentration of vermiculite to remove silicates. Air tables have been used, the separation being primarily according to size. The micaeous mineral turns its broad surface to the upward currents of air and is floated off the table. A third is the concentration of fullers earth with air tables to remove inert quartz particles. Many other instances might be cited.

Other raw materials of quite a different character that should be amenable to concentration methods are to be found in the cellulose pulp industry. All ground wood pulp contains mineral matter that is detrimental to whatever industry later receives the pulp, whether the paper, the nitration, the rayon, or other industry. Concentrating devices should be effective in removing deleterious materials, thus functioning in place of screens and centrifugal refiners.

In the paper industry are other raw materials to which concentration may be applied. When waste

paper is to be re-manufactured into paper, screens are commonly used to remove dirt, but screens naturally let considerable of this get into the system. A logical move would be to introduce an air table to treat the paper in a dry condition ahead of the beaters. The application would probably involve some dry preparation of the paper, perhaps a shredding operation to reduce it to a reasonably uniform size that could be handled efficiently on an air table.

## Applications in Manufacturing

Some possibilities for using concentration methods on raw materials for paper manufacture have been mentioned. Another opportunity appears early in the paper manufacturing process between the beaters and the jordsans. It is logical that as much dirt as possible should be removed from the pulp at this point, so that it may not be reduced to a finer size in the subsequent conditioning processes. Riffles are now being used, but they are a comparatively crude means of effecting a separation as compared to a modern concentrating device. As a check on this point, some preliminary trials were made on pulp from beaters with a wet concentrating table. As expected, the motion of the table was effective in loosening the paper pulp and made it possible for the fine dirt to settle between the table riffles, whence it was transported toward the concentrate end of the table. Without doubt, the standard ore table could be improved for this purpose.

In discussing the application of mechanical processes to the paper industry, it is interesting to note that this industry is now using a machine very much like a mechanical-type jig (the type using plungers to effect the pulsations in place of air, as in the Baum jig). The machine referred to is a diaphragm screen. As used in the paper industry, the pulsations work the paper fiber downward through slotted screens, while the impurities coarser than the screen openings remain above and are scraped from the screen with a flight conveyor, or removed periodically by hand. It is not hard to see how such an apparatus might be modified so that it would function as a jig and drop the fine waste materials through the screen plate while carrying over the cleaned fiber.

There seems also to be an oppor-

tunity for concentration methods in the starch industry in the separation of gluten from starch. The troughs now used appear to be in effect free-settling classifiers. It is doubtful whether any advantage is taken of the selective action of the horizontal currents. It should be possible by use of them to secure a sharper separation than now obtained.

Another group of operations in which concentration can play a part is the revivification of filter aids and decolorizing materials. A typical problem arises in treating the bone char used in the filtration of syrup. When this char is regenerated at high temperature, some of the particles become glazed and, therefore, inactive. However, these particles contain air and hence are of lower specific gravity than the balance of the char particles. Advantage may be taken of this to separate them for special treatment.

Some purely sizing operations may also be mentioned. In the polishing of plate glass, for example, carefully graded sands must be used for each stage of the polishing, and a similar problem arises in the manufacture of sand-paper and emery cloth. As stated earlier, hydraulic classifiers are excellent sizing devices on materials of one gravity.

## Applications to Waste Materials

This is a broad field with a score or more of possible applications from which a couple of examples may be cited. One is in washing sewage grit. This is primarily the removal of putrescible solids. A jiggling process, alternate upward and downward flow of water through the bed of particles, "scrubs" them, releasing adhering organic materials, which are discharged with the overflow water, while the cleaned grit is taken down through the screen and out through the concentrate draw. Results expressed in putrescible solids of from 1 to 2 per cent have been obtained, and the washed grit has been substantially free from particles that contribute to unsightly appearance.

Another waste product application is in the recovery of fiber from the waste water from paper mills. This material would normally be thickened, and then the thickened product could be submitted to some form of concentration to recover the fiber. This operation would also reduce the amount of waste being thrown into rivers.

## GRINDABILITY

(Continued from page 240)

a given material (assuming the pulverizer has already been calibrated by grinding a material of known characteristics), only a simple calculation is required. Using the grindability of the material, determination of the grindability component of the capacity factor (read on the ordinate) is made from Curve B in Fig. 1; then using the fineness desired, the fineness component of capacity factor (also read from the ordinate) is determined from Curve A. The product of these two is the capacity factor and by applying it to the calibrated capacity, an estimated output may be determined. Power requirement, based on an assumed 6 kw.-hr. per ton for the pulverizer alone, may be estimated as 6 divided by the capacity factor.

Practically, grindability has little effect on the total power cost. Comparing the cost of pulverizing coal of 100 grindability and coal of 45 grindability (an extreme case) showed that maintenance, power, and fixed charges amounted to a little over three cents per ton more for the latter coal (figuring power at 0.2c per kw.-hr.). So the general conclusion is that grindability tests find their chief use in deciding on proper size of equipment to install in a given plant and determining whether or not an existing installation has sufficient pulverizing capacity to carry the load with a given material.

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## MIXING STUDY

(Continued from page 245)

as cream," or "mixing a paste as thick as cheese." It is very difficult to work where so many methods are used for measuring viscosity and where results are expressed in different terms. For instance, the petroleum industry is inclined to the Saybolt system; whereas the rayon industry uses several different systems, time for falling balls of different sizes being the most common. Similar heterogeneity prevails in consistency measurements by various industries. Each industry, and in fact almost each company, has its own particular system, often understandable by no one else. However, the only way to produce designs better fitted to the purpose, and to eliminate many errors which are made constantly, is for the entire field to agree on a universal language. It would seem that there is no better system than the c.g.s. system and it has been shown (Chemical Engineers' Handbook, pp. 1270-1277) that not only viscosity but also apparent viscosity or consistency can be expressed in these terms.

When the work herein outlined has been completed, we will for the first time be able to talk about the "Science of Mixing."

## DIALYTIC SEPARATIONS

(Continued from page 255)

of the excess hemi. The process is working well, although the problems have not yet been entirely solved.

A possible application of great importance is in cane sugar refining, where both coloring matter and sugar values accumulate in the wash syrups, necessitating their final discarding for use in making industrial alcohol. Recent work on this molasses has shown that a large percentage of the sugar content is recoverable in crystallizable form by dialysis. Cellophane being excellent as a diaphragm material.

Another probably important application is in the textile field—recovery of mercerizing caustic. Not yet used here, dialysis would supplement the present methods of treating contaminated caustic and give a better product. At present, waste caustic is evaporated to high density, causing

a large part of the hemi-cellulose to precipitate out. The solids are removed by centrifugals or sand filters, the caustic being cooled, diluted and reused. It still contains much coloring matter and hemi, however, which in fine goods finishing tends to give a yellow cast. A possible flow sheet is suggested in the diagram appearing on page 255.

Many other applications are possible for dialysis, among which are the purifying of gels such as alumina and silica gel. Glue and gelatine may soon be purified in this fashion. Certain organic wastes may be flocculated by first removing dissolved salts by dialysis. Tartaric and citric acids may be recovered from citrus fruits by passage through diaphragms. Finally, although this by no means exhausts the list, later work may sometime result in a practical dialytic means for the virtual separation of crystalloidal salts in solution. Even with diffusion rates that are not widely separated, several stages of dialysis can effect a nearly complete separation. It is not too much to suppose that, as diaphragms are perfected, such processes will become commercially useful and economical.

## MAGNETIC SEPARATION

(Continued from page 276)

separators has been in the ceramic field, where iron contamination occurring as abraded iron, rust, or scale from containers, pipes, etc., and iron bearing minerals such as ilmenite, mica, etc., originating in the raw materials, is removed from clays, slips, glazes and enamels. The use of these machines is now being extended in many directions in the process industries. They are adaptable to a range of materials from the least viscous liquids up to heavy slurries that will hardly flow. Both capacity and efficiency depend somewhat on viscosity. At moderate and low viscosities quite fine screens are used.

Where they can be used, wet separators are preferred because of their high efficiency and low first and operating costs. The total cost averages between 2 and 4 cents per ton or per thousand gallons of liquid.

EDITOR'S NOTE:—Certain suggestions and illustration material for this article have been supplied through the courtesy of Dings Magnetic Separator Co., Stearns Magnetic Manufacturing Co., Exolon Co., and the author.

## Food and Drugs Bill in Revised Form

Complete revision of the original S-5 Food and Drugs bill as filed by Senator Copeland and passed by the Senate had been accomplished by the House Committee when that body finally on April 14, reported out the measure to the floor of the House.

Important among the changes made in committee is the addition to section 505, providing control of new drugs by forbidding sale unless an application to the Secretary of Agriculture has not been refused. That application must contain information giving the composition, manufacturing methods, result of investigations as to safety, and include samples and labels. The Secretary is required to give the applicant a hearing, and the applicant has the right to appeal from the decision of the Secretary to a Federal District Court.

Other alterations have been made in the pending bill. These include new administrative provisions. The Secretary of Agriculture is required to hold public hearings before amending regulations, and it is also provided that the regulations shall not become effective until 90 days after issue.

Section 403 (1) provides that whiskey is misbranded for purposes of the Revenue office, if it is made of any material except grain.

Senate and House conferees were still deadlocked at the close of the month, on the much disputed stream pollution measures. Though Capitol Hill would not talk about the undercurrent, it was learned that definite moves were under way to obtain a satisfactory compromise between the mandatory control provisions of Senator Lonerger's bill and the House measure.

Interests widely sundered in their character were reported working hard for this purpose. Among those named as seeking some sort of a workable compromise under which the legislation could be carried to completion, was Surgeon General Thomas Parran. Another interest, working independently of the Doctor, was a large paper pulp industry, which has had representatives on Capitol Hill for some months.

Industry is supporting the House Bill and is, for the most part, opposing the Lonerger measure.

## Manufacturing Chemists Will Meet at Skytop

The annual meeting and outing of the Manufacturing Chemists' Association will be held on June 2-3 at Skytop Lodge, Pa. In addition to the business sessions, committee reports, election of officers, etc., considerable time will be devoted to a review of the problems which confront the industry. The annual outing and golf tournament also are included in the two-day program. Members of the Synthetic Organic Chemical Manufacturers' Association will join in the outing and the golf tournament. At the union dinner of the two organizations, Bainbridge Colby, former secretary of state will be the principal speaker.

## Electrochemical Society Elects Officers

The annual meeting of the Electrochemical Society was held at Savannah, Ga., April 27-30. Symposia were held on the physico-chemical methods used in processing pulp and paper, industrial applications of electro-osmotic phenom-



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R. L. Baldwin

ena, electrodeposition of metals and principles of electrochemistry.

Officers elected for 1938-39 are: Robert L. Baldwin, National Carbon Co., Niagara Falls, N. Y., president; M. A. Veazey, Midland, Mich., A. Kenneth Graham, Philadelphia, Leon R. Westbrook, Cleveland, and S. Skowronski, Perth Amboy, N. J., vice presidents; R. B. Mears, New Kensington, Pa., H. E. Haring, Summit, N. J., and L. C. Judson, New York, N. Y., managers. Robert M. Burns and Colin G. Fink, both of New York, were re-elected treasurer and secretary, respectively.

The Weston Fellowship was awarded

to Vittorio De Nora, a native of Altamura, Italy, but at present carrying out research in electrometallurgy under Prof. Allison Butts, at Lehigh University, where he holds a Gotschall scholarship. The prize for the best paper presented before the Society during the past year by an author under 27 years of age was awarded R. Spencer Soanes of Toronto, Canada.

On the occasion of the Fifth Joseph W. Richards Memorial Lecture, Dr. Charles H. Herty, head of the Herty Foundation of Savannah, addressed the members and guests on the utilization of southern pine. Philip M. G. Shuey was chairman of the local committee.

## Japan Allocates Salt for Alkali Production

On the basis of a survey conducted by the Nikkan Shimbun, industrial salt consumption in Japan during the fiscal year ended March 31, 1938, amounted to 1,350,000 metric tons, of which Asahi Glass Co. received 420,000 tons, Tokuyama Soda, 380,000, Toyo Soda, 150,000, and Kyushu Soda, 50,000. Ammonia soda companies have utilized 1,024,000 tons during the year, and their estimated requirements for the 1938-39 fiscal year were submitted to the Government at 2,001,828 tons.

On March 11 the Salt Commission decided to limit consumption for the fiscal year 1938-1939 to 1,693,533 metric tons, an increase of 25 per cent from the previous year, but a reduction of 30 per cent from the estimated requirements. It seems likely, however, that the estimates of the various companies were placed rather higher than necessary, since it was almost certain that the Government would cut them.

## Larger Output of Bromine Last Year

Domestic production of bromine in 1937 amounted to 13,100 short tons, valued at \$5,180,177, compared with 10,305 tons, valued at \$4,038,438 in 1936. The total value of imports of bromine and bromine products in 1937 was \$225,268, 13 per cent less than in 1936.

Ethylene dibromide imported from Germany amounted to 983,075 pounds, worth \$190,190, a decrease of 22 per cent in quantity and 10 per cent in value.

Commercial sources in the United States include brine wells in California, Michigan, Ohio, and West Virginia, and seawater. The principal supply now comes from the ocean at Kure Beach, near Wilmington, N. C. The capacity of the North Carolina seaside plant was expanded in 1937 to recover bromine at the rate of 10,000 tons annually. A foreign seawater plant is now being considered, however, to be built on the island of Aruba, Dutch West Indies.

## Chemurgists Hold Meeting At Omaha

A three-day session was necessary to carry out the program arranged for the Fourth Annual Chemurgic Conference which was held at the Hotel Fontenelle, Omaha, Nebr., on April 25-27. Local and state officials made addresses at the opening luncheon on April 25. At the evening session talks on new products from farm materials included "Ethocel" by William Collins, Dow Chemical Co., "Sorbitol" by R. I. Bashford, Atlas Powder Co., "Furfural" by W. Courtney Wilson, Durite Plastics, "Wood Cellulose and Lignin" by E. C. Sherrard, Forest Products Laboratory, and "Walnut Shell Flour" by L. E. Pitner, Agicide Laboratories.

A soybean section was scheduled for April 26 and included discussions of the oil, oil meal, growers problems, work of the regional soybean industrial laboratory, and soybean glue. Agrol or power alcohol held a prominent place on the program. Wheeler McMillan in his address stressed the importance of this product and expressed the opinion that power alcohol would grow in the popular favor because of its scientific and economic merit and does not need the aid of legislation to extend sales. Leo M. Christensen, vice-president and general manager of the Atchison Agrol Co., spoke of the efforts that were being made to reduce costs of manufacturing and denaturing.

## M.I.T. Will Change Course In Electrochemistry

Changes in the Massachusetts Institute of Technology's courses in electrochemistry and mining engineering which will bring the advantages of the former to a larger number of students, and broaden the scope of training in the field of discovery and utilization of mineral resources, have been authorized by the executive committee of the Institute's corporation.

The Department of Chemical Engineering has been asked to undertake that part of the instruction and research in this field concerning substances other than the metals. With these plans in view the executive committee has authorized the discontinuance of the course in electrochemical engineering in June, 1940, after the present sophomores and juniors have completed the present curriculum.

## Illinois Schedules Glass Problems Conference

The Fifth Conference on Glass Problems will be held at the Department of Ceramic Engineering, University of Illinois, Urbana, Ill., on May 20-21. The conference will open on the afternoon of May 20 with C. W. Parmelee of the

## Elon H. Hooker

Elon H. Hooker, president of the Hooker Electrochemical Co., died on May 10 at Pasadena, Calif. Funeral services were held in Rochester, N. Y., where Mr. Hooker was born in 1869. After graduation from the University of Rochester, he studied engineering at Cornell and did post-graduate work in France and Switzerland. He then engaged in engineering work including construction of the Boston water supply system, the survey of Panama and Nicaragua canal routes, and in constructing a dam, water supply, and research laboratory for Cornell.

In 1903 he founded the Hooker Electrochemical Co. at Niagara Falls, of which he remained the head up to the time of his death. He was a former president of the Manufacturing Chemists' Association, chairman of the Research Corporation, member of executive committee of the National Industrial Conference Board, trustee of University of Rochester, director of National Association of Manufacturers, and a Knight of the Legion of Honor. He is survived by his widow and four daughters, a sister, and two brothers, Harry M. and Paul Hooker.

Department of Ceramic Engineering at Illinois as chairman. Glass Batch Problems will form the general theme for discussion and speakers will include A. D. Schiller, Corning Glass Wks., E. E. Milner, Ball Bros. Co., V. C. Fugman and H. I. Vormelker, General Electric Co., F. G. Schwalbe, Toledo Engineering Co., D. D. Burgess, Ball Bros. Co., Y. R. Cornelius, Englewood, N. J., and Z. C. Kline, General Electric Co.

On the morning of May 21, Glass Forming Molds will be the general topic with G. G. Hanson, Colorado Feldspar Co., presiding. Speakers will include G. B. Langer, Lynch Corp., J. S. Vanick, International Nickel Co., F. W. Dixon, Jr., Gunit Foundries Corp., and R. Szymanowitz, Acheson Colloids Corp.

## CALENDAR

AMERICAN PETROLEUM INSTITUTE, mid-year meeting, Wichita, Kansas, May 23-25.

SOCIETY OF CHEMICAL INDUSTRY, annual meeting of all sections, Ottawa, Canada, June 20-22.

AMERICAN SOCIETY FOR TESTING MATERIALS, annual meeting, Atlantic City, N. J., June 27-July 1.

AMERICAN CHEMICAL SOCIETY, semi-annual meeting, Milwaukee, Wis., Sept. 5-9.

TECHNICAL ASSOCIATION OF THE PULP AND PAPER INDUSTRY, semi-annual meeting, Green Bay, Wis., Sept. 8-10.

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS, semi-annual meeting, Philadelphia, Pa., Nov. 9-11.

## A.I.Ch.E. Student Chapters Meet at Knoxville

Nearly 200 chemical engineering students and faculty gathered at Knoxville, Tenn., on April 11 and 12 to participate in the second annual regional meeting of southeastern student chapters of the American Institute of Chemical Engineers. The University of Tennessee chapter of the Institute acted as host, and visiting delegates were registered from Alabama Polytechnic Institute, University of Alabama, University of Florida, Georgia School of Technology, University of Louisville, Mississippi State College, North Carolina State College, Virginia Polytechnic Institute, and University of Virginia.

In the student paper competition, which was a part of the program, first prize was won by Wallace F. Armstrong and Robert H. Culver of the University of Florida, and second prize went to N. W. Muller of Mississippi State College. Dr. R. L. Copson, principal chemical engineer of the T.V.A. Fertilizer Works at Wilson Dam, Ala., was judge of the contest, and the cash prizes were donated by Dr. Harry A. Curtis, chief chemical engineer of the T.V.A.

Virginia Polytechnic Institute at Blacksburg, Va., was selected as the location for the 1939 meeting of the southeastern A.I.Ch.E. student chapters.

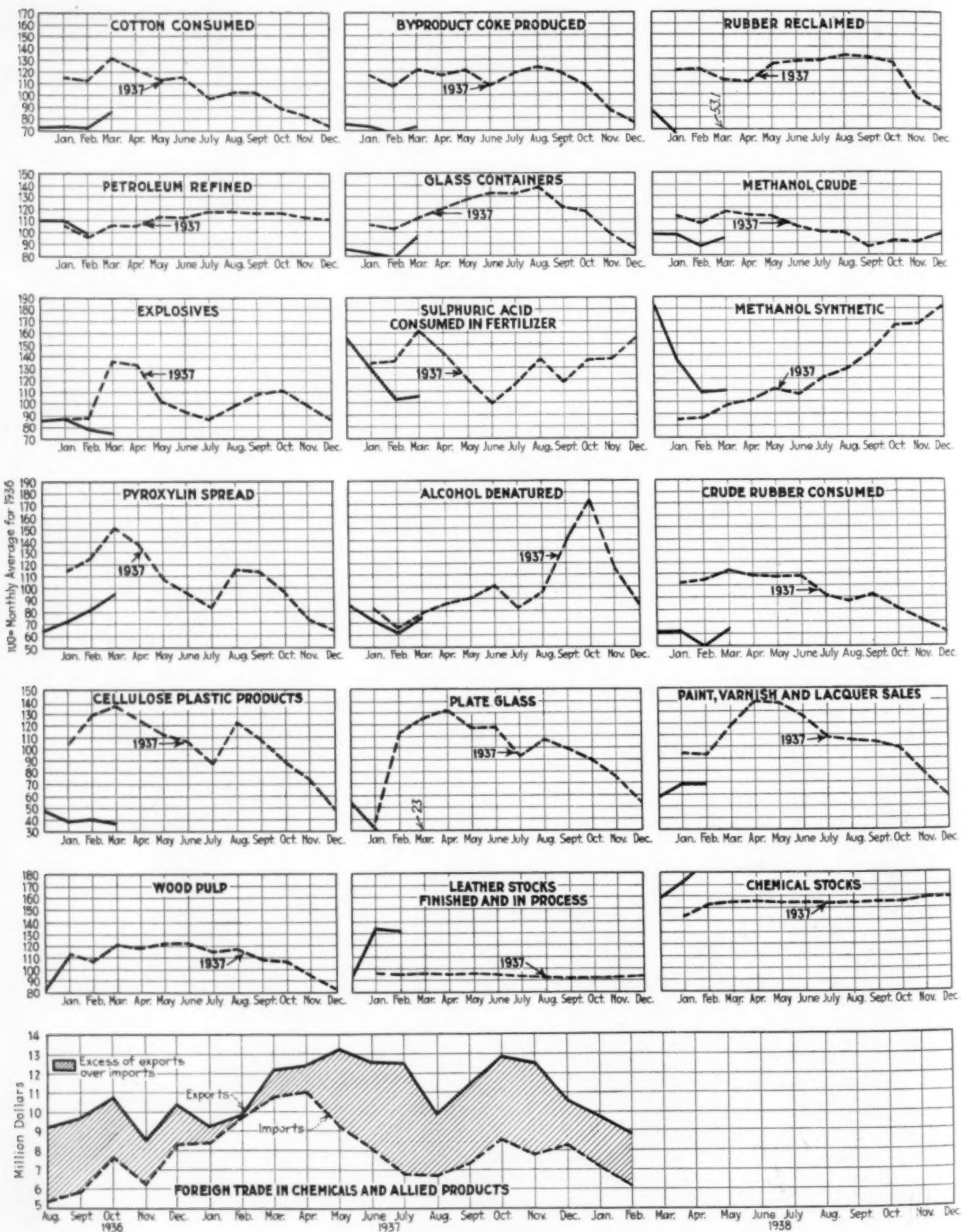
## Chemical Industries To Aid Greater New York Fund

Two committees are being formed in the chemical industries to cooperate in the 1938 campaign of the Greater New York Fund for contributions of \$10,000,000 to supplement finances of private welfare and health agencies. One of these committees, headed by Langbourne M. Williams, Jr., president of the Freeport Sulphur Co., will solicit the gifts of firms in the industry. J. Tyler Claiborne, Jr., vice-president of the Freeport Sulphur Company will be vice-chairman. The second committee, with Allen F. Kitchel, president of Binney & Smith Co., as chairman, will canvass employee groups.

## Dr. Newman Heads Chemical Engineering at C.C.N.Y.

Dr. Albert B. Newman has been appointed professor and head of the Department of Chemical Engineering of the School of Technology, College of the City of New York. Dr. Newman was graduated from the University of Michigan in 1910 with a B. A. degree. In 1911 he received the degree of Bachelor of Chemical Engineering; in 1926, the degree of Master of Science; and in 1928 he was made a Doctor of Philosophy in Chemical Engineering. From 1928 up to the present Dr. Newman had been head of the Chemical Engineering Department of Cooper Union.

# PRODUCTION AND CONSUMPTION TRENDS



# INDUSTRIAL CHEMICALS

	Current Price	Last Month	Last Year
Acetone, drums, lb.	\$0.051-\$0.061	\$0.051-\$0.061	\$0.06-\$0.07
Acid, acetic, 28%, bbl., cwt.	2.23-2.48	2.23-2.48	2.53-2.78
Glacial 99%, drums	8.43-8.68	8.43-8.68	8.70-8.95
U. S. P. reagent	10.25-10.50	10.25-10.50	10.75-11.00
Boric, bbl., ton	105.00-115.00	105.00-115.00	105.00-115.00
Citric, keg, lb.	.24-.27	.24-.27	.25-.28
Formic, bbl., ton	.101-.11	.101-.11	.11-.111
Gallie, tech., bbl., lb.	.75-.78	.75-.78	.60-.65
Hydrofluoric 30% carb., lb.	.07-.071	.07-.071	.07-.071
Lactic, 44%, tech., light, bbl., lb.	.061-.061	.061-.061	.61-.61
Muriatic, 18%, tanks, cwt.	1.05-.051	1.05-.051	1.00-1.10
Nitric, 36%, carboys, lb.	.05-.051	.05-.051	.05-.051
Oleum, tanks, wks., ton	18.50-20.00	18.50-20.00	18.50-20.00
Oxalic, crystals, bbl., lb.	.101-.12	.101-.12	.101-.12
Phosphoric, tech., c'by., lb.	.09-.10	.09-.10	.09-.10
Sulphuric, 60%, tanks, ton	13.00-13.00	13.00-13.00	11.00-11.50
Sulphuric, 66%, tanks, ton	16.50-16.50	16.50-16.50	15.50-15.50
Tannic, tech., bbl., lb.	.40-.45	.40-.45	.26-.30
Tartaric, powd., bbl., lb.	.251-.26	.251-.26	.221-.23
Tungstic, bbl., lb.	2.75-2.75	2.75-2.75	2.50-2.75
Alcohol, Amyl.	1.23-1.23	1.23-1.23	1.23-1.23
From Pentane, tanks, lb.	.081-.081	.081-.081	.081-.081
Alcohol, Butyl, tanks, lb.	4.11-4.11	4.11-4.11	4.14-4.14
Alcohol, Ethyl, 190p.f., bbl., gal.	.31-.31	.31-.31	.32-.32
Denatured, 190 proof	.031-.04	.031-.04	.03-.04
No. 1 special, dr., gal wks.	1.35-1.50	1.35-1.50	1.35-1.50
Alum, ammonia, lump, bbl., lb.	2.00-2.25	2.00-2.25	2.00-2.25
Potash, lump, bbl., lb.	.021-.03	.021-.03	.021-.03
Aluminum sulphate, com bags, cwt.	.021-.021	.021-.021	.021-.021
Iron free, bg., cwt.	.15-.16	.15-.16	.15-.16
Aqua ammonia, 26%, drums, lb.	.041-.041	.041-.041	.041-.041
tanks, lb.	.08-.12	.08-.12	.08-.12
Ammonia, anhydrous, cyl., lb.	1.475-1.475	1.475-1.475	1.35-1.50
Ammonium carbonate, powd, tech., casks, lb.	.11-.12	.11-.12	.11-.111
Sulphate, wks., cwt.	.121-.13	.121-.13	.16-.161
Amylacetate tech., tanks, lb.	.03-.031	.03-.031	.03-.031
Antimony Oxide, bbl., lb.	.151-.16	.151-.16	.151-.16
Arsenic, white, powd., bbl., lb.	52.50-57.50	52.50-57.50	56.50-58.00
Red, powd., keg, lb.	79.00-81.00	79.00-81.00	72.00-74.00
Barium carbonate, bbl., ton	.07-.08	.07-.08	.081-.09
Chloride, bbl., ton	.031-.04	.031-.04	.031-.04
Nitrate, cask, lb.	2.00-2.10	2.00-2.10	2.00-2.10
Blanc fixe, dry, bbl., lb.	46.00-51.00	46.00-51.00	44.00-49.00
Bleaching powder, f. o. b., wks., drums, cwt.	.30-.32	.30-.32	.36-.38
Borax, gran., bags, ton	1.65-1.65	1.65-1.65	2.25-2.25
Bromine, os., lb.	.061-.07	.061-.07	.061-.07
Calcium acetate, bags	.05-.06	.05-.06	.05-.06
Arenate, dr., lb.	21.50-24.50	21.50-24.50	20.00-33.00
Carbide drums, lb.	23.00-25.00	23.00-25.00	22.00-35.00
Chloride, fused, dr., del., ton	.071-.08	.071-.08	.071-.08
flake, dr., del., ton	.05-.06	.05-.06	.051-.06
Phosphate, bbl., lb.	.051-.081	.051-.06	.051-.06
Carbon bisulphide, drums, lb.	2.15-2.15	2.15-2.15	2.15-2.15
Tetrachloride drums, lb.	.051-.06	.051-.06	.051-.06
Chlorine, liquid, tanks, wks., lb.	1.67-1.70	1.67-1.70	1.41-1.51
Cylinders	15.00-16.00	15.00-16.00	15.00-16.00
Cobalt oxide, cans, lb.	.09-.161	.09-.161	.111-.16
Copperas, bags, f.o.b., wks., ton	4.25-4.50	4.25-4.50	5.40-5.65
Copper carbonate, bbl., lb.	.201-.21	.201-.21	.161-.17
Sulphate, bbl., cwt.	.22-.23	.22-.23	.22-.23
Creosote of tartar, bbl., lb.	1.80-2.00	1.80-2.00	1.80-2.00
Diethylene glycol, dr., lb.	.061-.061	.061-.061	.061-.061
Epsom salt, dom., tech., bbl., cwt.	.051-.061	.051-.061	.051-.061
Ethyl acetate, drums, lb.	.10-.171	.10-.171	.10-.171
Formaldehyde, 40%, bbl., lb.	.16-.18	.16-.18	.16-.18
Furfural, dr., lb.	.95-1.00	.95-1.00	.85-1.00
Fuel oil, ref. drums, lb.	.151-.151	.151-.151	.251-.251
Glauber salt, bags, cwt.	.061-.061	.061-.061	.061-.061
Glycerine, c.p., drums, extra, lb.	.061-.061	.061-.061	.061-.061
Lead:			
White, basic carbonate, dry casks, lb.	.051-.051	.051-.051	.071-.071
White, basic sulphate, sek., lb.	.07-.07	.07-.07	.081-.081
Red, dry, sek., lb.	.11-.12	.11-.12	.131-.14
Lead acetate, white crys., bbl., lb.	.13-.131	.13-.131	.111-.12
Lead arsenate, powd., bbl., lb.	8.50-8.50	8.50-8.50	8.50-8.50
Lime, chem., bulk, ton	.06-.06	.06-.06	.071-.071
Litharge, powd., csk., lb.	.041-.041	.041-.041	.041-.05
Lithophone, bags, lb.	.06-.061	.06-.061	.06-.061
Magnesium carb., tech., bags, lb.			

The accompanying prices refer to round lots in the New York market. Where it is the trade custom to sell f.o.b. works, quotations are given on that basis and are so designated. Prices are corrected to May 14

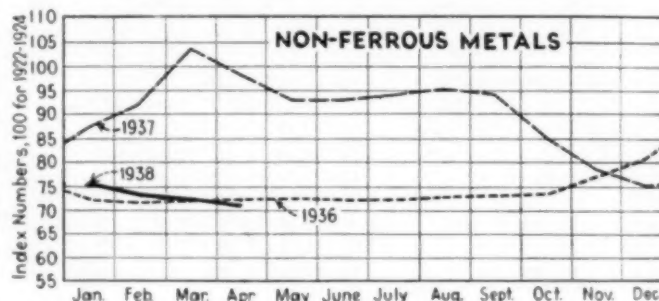
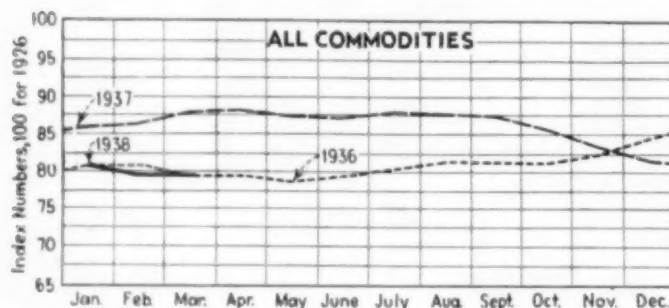
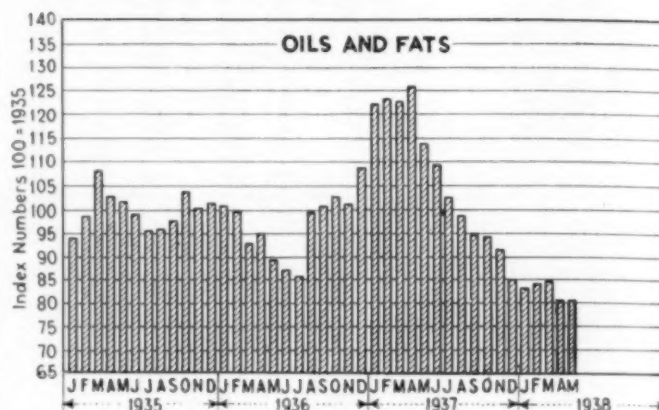
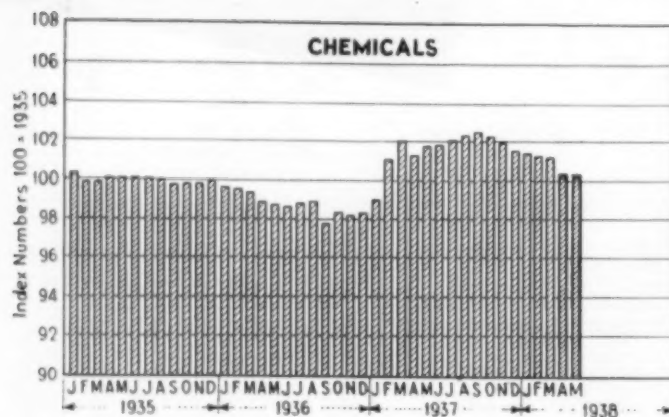
## Current PRICES

	Current Price	Last Month	Last Year
Methanol, 95%, tanks, gal.	.31-.31	.31-.31	.33-.33
97%, tanks, gal.	.32-.32	.32-.32	.34-.34
Synthetic, tanks, gal.	.33-.33	.33-.33	.33-.33
Nickel salt, double, bbl., lb.	.13-.131	.13-.131	.13-.131
Orange mineral, csk., lb.	.10-.10	.10-.10	.111-.111
Phosphorus, red, cases, lb.	.40-.42	.40-.42	.40-.42
Yellow, cases, lb.	.24-.30	.24-.30	.24-.30
Potassium bichromate, casks, lb.	.081-.09	.081-.09	.081-.09
Carbonate, 80-85%, calc. csk., lb.	.061-.061	.061-.061	.07-.071
Chlorate, powd., lb.	.091-.091	.091-.091	.081-.09
Hydroxide (caustic potash) dr., lb.	.07-.071	.07-.071	.07-.071
Muriate, 80% bags, ton	23.00-23.00	23.00-23.00	23.00-23.00
Nitrate, bbl., lb.	.051-.06	.051-.06	.051-.06
Permanganate, drums, lb.	.181-.19	.181-.19	.181-.19
Prussate, yellow, casks, lb.	.15-.16	.15-.16	.15-.16
Sol ammoniac, white, casks, lb.	.05-.051	.05-.051	.05-.051
Salsoda, bbl., cwt.	1.00-1.05	1.00-1.05	1.00-1.05
Salt cake, bulk, ton	13.00-15.00	13.00-15.00	13.00-15.00
Soda ash, light, 58%, bags, contract, cwt.	1.23-1.23	1.23-1.23	1.23-1.23
Dense, bags, cwt.	1.25-1.25	1.25-1.25	1.25-1.25
Soda, caustic, 76%, solid, drums, contract, cwt.	2.60-3.00	2.60-3.00	2.60-3.00
Acetate, works, bbl., lb.	.04-.05	.04-.05	.041-.05
Bicarbonate, bbl., cwt.	1.75-2.00	1.75-2.00	1.75-2.00
Bichromate, casks, lb.	.061-.07	.061-.07	.061-.07
Bisulphate, bulk, ton	15.00-16.00	15.00-16.00	15.00-16.00
Bisulphite, bbl., lb.	.031-.04	.031-.04	.031-.04
Chlorate, keg, lb.	.061-.061	.061-.061	.061-.061
Chloride, tech., ton	12.00-14.75	12.00-14.75	12.00-14.75
Cyanide, cases, dom., lb.	.14-.15	.161-.17	.161-.17
Fluoride, bbl., lb.	.071-.08	.071-.08	.071-.08
Hyposulphite, bbl., cwt.	2.40-2.50	2.40-2.50	2.40-2.50
Metasilicate, bbl., cwt.	2.20-3.20	2.20-3.20	2.15-3.15
Nitrate, bags, cwt.	1.45-1.45	1.45-1.45	1.375-1.375
Nitrite, casks, lb.	.07-.08	.07-.08	.071-.08
Phosphate, dibasic, bags, lb.	1.85-1.85	1.85-1.85	.022-.024
Prussiate, yel. drums, lb.	.10-.11	.10-.11	.10-.11
Silicate (40% dr.) wks., cwt.	.80-.85	.80-.85	.80-.85
Sulphide, fused, 60-62%, dr., lb.	.021-.031	.021-.03	.021-.03
Sulphite, cys., bbl., lb.	.021-.021	.021-.021	.021-.021
Sulphur, crude at mine, bulk, ton	18.00-18.00	18.00-18.00	18.00-18.00
Chloride, dr., lb.	.03-.04	.03-.04	.031-.04
Dioxide, cyl., lb.	.07-.08	.061-.08	.07-.071
Flour, bag, cwt.	1.60-3.00	1.60-3.00	1.60-3.00
Tin Oxide, bbl., lb.	.46-.47	.47-.47	.58-.58
Crysalis, bbl., lb.	.32-.321	.321-.321	.40-.40
Zinc chloride, gran., bbl., lb.	.05-.06	.05-.06	.05-.06
Carbonate, bbl., lb.	.14-.15	.14-.15	.09-.11
Cyanide, dr., lb.	.33-.35	.36-.38	.36-.38
Dust, bbl., lb.	.061-.061	.061-.061	.081-.081
Zinc oxide, lead free, bags, lb.	.061-.061	.061-.061	.061-.061
5% lead sulphate, bags, lb.	.061-.061	.061-.061	.051-.051
Sulphate, bbl., cwt.	3.15-3.60	3.15-3.60	3.15-3.60

## OILS AND FATS

	Current Price	Last Month	Last Year
Castor oil, No. 3, bbl., lb.	\$0.091-\$0.10	\$0.091-\$0.10	\$0.10-\$0.11
Chinawood oil, bbl., lb.	.12-.12	.12-.12	.14-.14
Cocoonut oil, Ceylon, tanks, N. Y. lb.	.031-.031	.031-.031	.071-.071
Corn oil crude, tanks (f.o.b. mill), lb.	.071-.071	.071-.071	.09-.09
Cottonseed oil, crude (f.o.b. mill), tanks, lb.	.07-.07	.07-.07	.081-.081
Linseed oil, raw car lots, bbl., lb.	.093-.093	.093-.093	.113-.113
Palm, casks, lb.	.036-.036	.04-.04	.06-.06
Peanut oil, crude, tanks (mill), lb.	.071-.071	.071-.071	.091-.091
Rapeseed oil, refined, bbl., gal.	.85-.85	.88-.88	.93-.93
Soya bean, tank, lb.	.051-.051	.06-.06	.09-.09
Sulphur (olive foots), bbl., lb.	.081-.081	.081-.081	.12-.12
Cod, Newfoundland, bbl., gal.	.52-.52	.52-.52	.51-.51
Menhaden, light pressed, bbl., lb.	.081-.081	.081-.081	.09-.09
Crude, tanks (f.o.b. factory), gal.	.35-.35	.35-.35	.43-.43
Grease, yellow, loose, lb.	.041-.041	.041-.041	.081-.081
Oleo stearine, lb.	.071-.071	.071-.071	.091-.091
Oleo oil, No. 1	.081-.081	.09-.09	.15-.15
Red oil, distilled, d.p. bbl., lb.	.091-.091	.091-.091	.101-.101
Tallow extra, loose, lb.	.051-.051	.051-.051	.081-.081

# CHEM. & MET.'S WEIGHTED PRICE INDEXES



## COAL-TAR PRODUCTS

	Current Price	Last Month	Last Year
Alpha-naphthol, crude, bbl., lb.	\$0.52 - \$0.55	\$0.52 - \$0.55	\$0.52 - \$0.55
Alpha-naphthylamine, bbl., lb.	.32 - .34	.32 - .34	.32 - .34
Aniline oil, drums, extra, lb.	.15 - .16	.15 - .16	.15 - .16
Aniline salts, bbl., lb.	.22 - .24	.22 - .24	.24 - .25
Benzaldehyde, U.S.P., dr., lb.	.85 - .95	.85 - .95	1.10 - 1.25
Benzidine base, bbl., lb.	.70 - .75	.70 - .75	.65 - .67
Benzoic acid, U.S.P., kgs., lb.	.54 - .56	.54 - .56	.52 - .54
Benzyl chloride, tech., dr., lb.	.25 - .27	.25 - .27	.25 - .27
Benzol, 90%, tanks, works, gal.	.16 - .18	.16 - .18	.16 - .18
Beta-naphthol, tech., drums, lb.	.23 - .24	.23 - .24	.23 - .24
Cresol, U.S.P., dr., lb.	.12 - .13	.12 - .13	.10 - .11
Cresylic acid, 99%, dr., wks., gal.	.87 - .89	.87 - .89	.90 - 1.00
Diethylaniline, dr., lb.	.40 - .45	.40 - .45	.55 - .58
Dinitrophenol, bbl., lb.	.23 - .25	.23 - .25	.23 - .25
Dinitrotoluen, bbl., lb.	.15 - .16	.15 - .16	.15 - .16
Dip oil, 15%, dr., gal.	.23 - .25	.23 - .25	.23 - .25
Diphenylamine, bbl., lb.	.32 - .36	.32 - .36	.32 - .36
H-acid, bbl., lb.	.50 - .55	.50 - .55	.50 - .55
Naphthalene, flake, bbl., lb.	.06 - .07	.06 - .07	.07 - .07
Nitrobenzene, dr., lb.	.08 - .09	.08 - .09	.08 - .10
Para-nitraniline, bbl., lb.	.50 - .52	.50 - .52	.45 - .47
Phenol, U.S.P., drums, lb.	.14 - .15	.14 - .15	.13 - .14
Picric acid, bbl., lb.	.35 - .40	.35 - .40	.30 - .40
Pyridine, dr., gal.	1.55 - 1.60	1.55 - 1.60	1.30 - 1.35
Resorcinol, tech., kgs., lb.	.75 - .80	.75 - .80	.75 - .80
Salicylic acid, tech., bbl., lb.	.33 - .40	.33 - .40	.34 - .40
Solvent naphtha, w.w., tanks, gal.	.30 - .30	.30 - .30	.30 - .30
Tolidine, bbl., lb.	.88 - .90	.88 - .90	.88 - .90
Toluene, tanks, works, gal.	.35 - .35	.35 - .35	.35 - .35
Xylene, com, tanks, gal.	.35 - .35	.35 - .35	.35 - .35

## MISCELLANEOUS

	Current Price	Last Month	Last Year
Barytes, grd., white, bbl., ton.	\$22.00 - \$25.00	\$22.00 - \$25.00	\$22.00 - \$25.00
Casein, tech., bbl., lb.	.06 - .12	.07 - .12	.13 - .15
China clay, dom., f.o.b. mine, ton.	8.00 - 20.00	8.00 - 20.00	8.00 - 20.00
Dry colors			
Carbon gas, black (wks.), lb.	.02 - .30	.02 - .30	.04 - .30
Prussian blue, bbl., lb.	.36 - .37	.36 - .37	.37 - .38
Ultramarine blue, bbl., lb.	.10 - .26	.10 - .26	.10 - .26
Chrome green, bbl., lb.	.21 - .30	.21 - .30	.26 - .27
Carmine red, tins, lb.	4.00 - 4.40	4.00 - 4.40	4.00 - 4.40
Para toner, lb.	.75 - .80	.75 - .80	.75 - .88
Vermilion, English, bbl., lb.	1.45 - 1.50	1.45 - 1.50	1.72 - 1.75
Chrome yellow, C. P., bbl., lb.	.14 - .15	.14 - .15	.13 - .14
Feldspar, No. 1 (f.o.b. N.C.), ton.	6.50 - 7.50	6.50 - 7.50	6.50 - 7.50
Graphite, Ceylon, lump, bbl., lb.	.06 - .06	.06 - .06	.06 - .06
Gum copal Congo, bags, lb.	.06 - .30	.06 - .30	.08 - .30
Mazila, bags, lb.	.07 - .14	.07 - .14	.09 - .14
Damar, Batavia, cases, lb.	.16 - .24	.16 - .24	.15 - .16
Kauri cases, lb.	.17 - .60	.17 - .60	.19 - .25
Kieselguhr (f.o.b. N. Y.), ton.	50.00 - 55.00	50.00 - 55.00	50.00 - 55.00
Magnesite, calc, ton.	50.00 - .	50.00 - .	50.00 - .
Pumice stone, lump, bbl., lb.	.05 - .07	.05 - .08	.05 - .07
Imported, caaks, lb.	.03 - .04	.03 - .04	.03 - .04
Rosin, H., bbl.	5.85 - .	6.10 - .	9.55 - .
Turpentine, gal.	.29 - .	.28 - .	.42 - .
Shellac, orange, fine, bags, lb.	.20 - .	.20 - .	.24 - .
Bleached, bonedry, bags, lb.	.16 - .	.16 - .	.19 - .
T. N. Bags, lb.	.11 - .	.11 - .	.13 - .
Soapstone (f.o.b. Vt.), bags, ton.	10.00 - 12.00	10.00 - 12.00	10.00 - 12.00
Talc, 200 mesh (f.o.b. Vt.), ton.	8.00 - 8.50	8.00 - 8.50	8.00 - 8.50
300 mesh (f.o.b. Ga.), ton.	7.50 - 10.00	7.50 - 10.00	7.50 - 11.00
225 mesh (f.o.b. N. Y.), ton.	13.75 - .	13.75 - .	13.75 - .

## INDUSTRIAL NOTES

H. R. NELSON, chemical engineer formerly located at 95 Liberty St., New York, has moved to 286 North Broad St., Elizabeth, N. J.

GENERAL ALLOYS CO., Boston, has appointed the Ladd Equipment Co., First National Bank Bldg., Pittsburgh, as its representatives for western Pennsylvania, West Virginia, western Ohio, and Garrett and Allegany Counties in Maryland.

AMERICAN DISTRICT STEAM CO., North Tonawanda, N. Y., is now represented in

Eastern Pennsylvania by the Sheffer-Gross Co., with offices in the Drexel Bldg., Philadelphia.

U. S. INDUSTRIAL ALCOHOL CO., New York, has taken over the business and the plant of Robert Rau, Inc., Newark, N. J. The plant will continue to produce a diversified line of resins.

THE COCHRANE CORP., Philadelphia, has appointed the C. J. Gaskell Co., Memphis, Tenn., as its representative in Arkansas, Western Tennessee, and Northern Mississippi.

CALCO CHEMICAL CO., INC., Bound Brook, N. J., has purchased The Amalgamated Dye-stuff & Chemical Works, Inc., Newark, N. J. and John Campbell and Co., New York.

DEVOS & RAYMONDS CO., New York, has approved plan to take over the Jones-Dabney Co., paint manufacturers at Louisville and Detroit.

CONNECTICUT BLOWER CO., Hartford, Conn., has appointed Edw. F. Klick, Rochester, N. Y., as special sales engineer for the state of New York.

## Where Plants Are Being Built in Process Industries

	Current Projects		Cumulative 1938	
	Proposed Work	Contracts	Proposed Work	Contracts
New England.....	\$80,000	\$182,000	\$240,000	\$712,000
Middle Atlantic.....	230,000	330,000	4,969,000	1,688,000
South.....	7,000,000	1,140,000	15,980,000	1,240,000
Middle West.....	1,572,000	230,000	12,077,000	3,420,000
West of Mississippi...	595,000	140,000	7,940,000	4,600,000
Far West.....	40,000	.....	870,000	2,172,000
Canada.....	240,000	1,540,000	10,845,000	2,210,000
Total.....	\$9,757,000	\$3,562,000	\$52,921,000	\$16,042,000

### PROPOSED WORK

**Calfskin Factory**—A. C. Lawrence Leather Co., Sawyer St., Peabody, Mass., is receiving bids for the construction of a 1 story, 75x170 ft. addition to its calfskin factory. Estimated cost including equipment \$40,000.

**Chemical Plant**—Arizona Chemical Co., Brownfield, Tex., plans to construct a 2 story chemical plant at Brownfield. Sodium sulphate will be mined and after processed will be used for refining purposes, etc. Machinery and equipment for mining and processing will be purchased and installed. Estimated cost \$70,000.

**Chemistry Building**—Case School of Applied Science, George E. Van Dyke, Secy., Treas., Euclid Ave., Cleveland, O., contemplates the construction of a Chemistry Building. Walker & Weeks, 2341 Carnegie Ave., Cleveland, Archts. Estimated cost \$600,000.

**Chemistry Building**—Miami University, Oxford, O., plans to construct west wing of Chemistry Building. State Legislature has appropriated \$100,000. W.P.A. grant for \$67,000 additional has been requested for construction of east wing.

**Concrete Mixing Plant**—McMichael Concrete Co., Lubbock, Tex., plans to construct a 1 story, 100 x 100 ft. concrete mixing plant. Owner may build with own forces.

**Distillery**—Schenley Products Co., 451 Montgomery St., San Francisco, Calif., plans to construct a bottling plant at its distillery to cover 100,000 sq. ft., at Battery and Vallejo Sts., San Francisco.

**Factory**—Agfa Ansco Corp., Charles St., Binghamton, N. Y., plans to construct a 4 story, 73x162 ft. addition to Building No. 43. Bids are now being received by Lockwood Greene Engineers, Inc., 30 Rockefeller Plaza, New York, N. Y. Estimated cost \$150,000.

**Factory**—Parke, Davis & Co., McDougal St., Detroit, Mich., plans to construct a 7 story factory addition. Albert Kahn, New Center Bldg., Detroit, Archt.

**Factory**—Wollensack Optical Co., Hudson Ave., Rochester, N. Y., plans to construct a 1 story addition to its factory. L. J. Ribson, 73 Wilmer St., Rochester, Archt.

**Fertilizer Plant**—F. S. Royster Guano Co., C. F. Burroughs, Pres., Royster Bldg., Norfolk, Va., is having plans prepared by E. C. Doeppers Co., 923 Law Bldg., Indianapolis, Ind., for the construction of a 1 story, 240x430 ft. (3 levels) fertilizer plant consisting of ten buildings, south of Kentucky Ave. between Harding St. and Eagle Creek, Indianapolis, Ind. A. L. Griffin, Norfolk, is chief engineer for Company. Estimated cost \$500,000.

**Galvanizing Plant**—Joslyn Manufacturing & Supply Co., 3700 South Morgan St., Chicago, Ill., plans to construct an addition to its galvanizing plant. Bids are now being received by W. C. Walker, Archt., 207 North Michigan, Chicago. Estimated cost \$40,000.

**Gas Plant**—Del Ray Producing Co., R. R. Dean, Vice Pres., Brazoria, Tex., plans to construct a gas plant to have a daily capacity of 18,000,000 cu. ft. at Sandy Point near Brazoria. Estimated cost between \$80,000 and \$100,000.

**Gas Plant**—Key City Gas Co., Dubuque, Ia., plans improvements to its gas plant. Estimated cost \$75,000.

**Oil Refinery**—C. H. Lebow et al., Wichita, Kan., contemplates the construction of an oil refinery in the Bemis Pool section of

Ellis County near Hays, Kan., to have a capacity of 15,000 bbl. Construction will be contingent on increase in allowables for Bemis Pool. Project is under consideration by Kansas Corporation Commission.

**Oil and Gasoline Plant**—Shamrock Oil & Gas Co., Amarillo, Tex., is having preliminary surveys made for the construction of a plant to extract various types of oil and gasoline from natural gas in Hidalgo Co., Edinburg, Tex. Estimated cost \$250,000.

**Paper Mill**—Ecusta Paper Corp. of Delaware, Harry S. Strauss, Pres., c/o Champagne Paper Corp., 345 West 40th St., New York, N. Y., has purchased a site of 225 acres in Transylvania Co. near Pisgah Forest Reservation 2½ mi. north of Brevard, N. C., and plans to construct a plant for the manufacture of cigarette paper. J. E. Serrine & Co., Greenville, S. C., Engr. Estimated cost \$2,000,000.

**Paper Mill**—Hollingsworth & Whitney Co., 140 Federal St., Boston, Mass., has acquired a site at the Alabama State Docks Properties at Mobile, Ala., and plans to construct a paper mill. The Company has closed a 99 year lease for the site. Estimated cost \$5,000,000.

**Pulp Handling Plant**—Ontario Paper Co., Thorold, Ont., Can., owned by the Chicago Tribune, 435 North Michigan Ave., Chicago, Ill., contemplates the construction of a pulp handling plant, power house, etc., at Heron Bay, Ont., Can. Estimated cost \$200,000.

**Processing Plant**—Davenport Processing Co., Greenwich, Conn., contemplates the construction of a plant to replace the one recently damaged by fire. Estimated cost \$40,000.

**Roofing Felt Factory**—Electric City Paper Mills, Niagara Falls, N. Y., manufacturers of roofing felt, plan to repair their plant here. Estimated cost including equipment \$40,000.

**Sewer Pipe Factory**—Stillwater Clay Products Co., James Duffy, Secy., Uhrichsville, O., manufacturers of sewer pipe, plans to rebuild its factory which was recently destroyed by fire with a loss of \$150,000.

**Soy Bean Plant**—Ford Motor Co., Schaefer Rd., Dearborn, Mich., is having preliminary plans prepared by Shreve, Anderson & Walker, Archts., 914 Marquette Bldg., Detroit, Mich., for a soy bean plant. Estimated cost \$75,000.

**Sulphur Deposit Development**—Freeport Sulphur Co., 122 East 42nd St., New York, N. Y., contemplates a sulphur deposit development in Washington and Austin Counties, Tex. The Company has 1,200 acres under lease. Estimated cost will exceed \$40,000.

**Smelter**—Consolidated Mining & Smelting Co. of Canada, Ltd., 215 St. James St., Montreal, Que., Can., plans to construct a concentrator and smelter in the Chibougamau District of Quebec. J. J. Warren, Gen. Mgr.

### CONTRACTS AWARDED

**Acetylene Plant**—Compressed Industrial Gases, Inc., R. C. Everson, Engr., Evansville, Ind., has awarded the contract for the construction of an acetylene plant near Conshohocken, Pa., to Frank R. Heavener, Montgomery Trust Arcade, Norristown, Pa. Estimated cost \$250,000.

**Chemistry Building**—Bilhuber Knoel Corp., 154 Ogden St., Jersey City, N. J., has awarded the contract for the construction of a 3 story, 52 x 183 ft. chemistry building at Orange, N. J., to William J. Barney, 101 Park Ave., New York, N. Y.

**Factory**—Johns-Manville Co., 22 East 40th St., New York, N. Y., will construct a plant for the manufacture of insulating board products at Jarrett, Va. Stone & Webster, Consulting Engrs., 90 Broad St., New York, N. Y., will be in charge of design and construction of the plant. Estimated cost \$1,000,000.

**Factory**—Northwestern Yeast Foam Co., 1750 North Ashland Ave., Chicago, Ill., has awarded the contract for the construction of a 3 story factory to Kaiser-Ducett Co., 80 East Jackson St., Chicago. Estimated cost \$100,000.

**Gas Plant**—New Haven Gas Light Co., 80 Crown St., New Haven, Conn., will construct additions to its gas plant and distribution lines. Work will be done by day labor and separate contracts. Estimated cost \$130,000.

**Glass Factory**—Wharton Glass Manufacturing Co., Wharton, Tex., will construct a modern 1 and 2 story glass factory. Work will be done by day labor and separate contracts. Owners will purchase machinery and equipment. Estimated cost will exceed \$40,000.

**Oil Refinery**—Globe Oil & Refining Co., Lemont, Ill., plans to recondition its oil refinery. Separate contracts have been awarded for the work. Estimated cost will exceed \$40,000.

**Oil Refinery**—Maritime Oil Co., 2009 Noble St., Houston, Tex., has awarded the contract for an oil refinery to Mid Continent Engineering Co., First Natl. Bank Bldg., Dallas, Tex. Estimated cost \$100,000.

**Phosphate Mining Plant**—Warren-Turner Co., Warsaw, N. C., recently organized by S. L. Warren and J. J. Whitehurst of Mt. Olive, N. C., P. R. Turner, Warsaw, and Henry Vann, Clinton, N. C., will construct a large mining plant to mine commercial lime and phosphate in a large area located on Stuart's Creek on Duplan-Sampson Co. line, 4½ mi. southwest of Warsaw.

**Ore Mill**—International Nickel Co., Donald McAnkill, Gen. Mgr., Sudbury, Ont., Can., has awarded the contract for steel for a low grade ore mill to Dominion Bridge Co., 1139 Shaw St., Toronto, Ont., Can. Total estimated cost \$1,500,000.

**Tunnel Kiln**—Mayfair Potteries, Inc., Carrollton, O., recently incorporated, has awarded the contract for a tunnel kiln to Allied Engineering Co., 4150 East 56th St., Cleveland. Estimated cost \$50,000. The Company has acquired the plant of the former Albright China Co.

**Concentrator**—Francoeur Gold Mines, Ltd., 1010 St. Catherine St. W., Montreal, Que., Can., has awarded the contract for a 150 ton concentrator at Beauchastle Mine to Hill, Francis-Clarke, Ltd., Noranda, Ont.

**Distribution and Storage Building**—Devoo & Reynolds Co., 78 Broad St., N. W., Atlanta, Ga., paint manufacturers, has awarded the contract for a storage and distribution building at Miami, Fla., to Gunn & Goll, 69 N.E. 36th St., Miami, Fla. Estimated cost \$40,000.

**Warehouse**—Cedar Valley Distillery Co., Wooster, O., has awarded the contract for a warehouse and improvements to its distillery to L. L. Webb, Wooster. Estimated cost will exceed \$40,000.

**Warehouse**—General Aniline Works, Inc., 435 Hudson St., New York, N. Y., has awarded the contract for a warehouse at Rensselaer, N. Y., to William G. Sheehan Construction Co., Inc., 28 DeWitt St., Albany. Estimated cost will exceed \$40,000.

**Warehouse**—Pittsburgh Plate Glass Co., 300 Babcock St., Allston, Mass., has awarded the contract for a 1 story, 150 x 170 ft. warehouse on Harris Ave., Providence, R. I., to E. Turgeon, 36 Exchange Pl., Providence. Estimated cost \$52,000.

# Only Moderate Gains Reported In Movement of Chemicals

FROM statistical data now available it becomes evident that while the chemical industry during the first quarter of this year fell considerably below the levels reached in the first quarter of last year, the degree of decline showed wide fluctuations for different branches of the industry. The decline in the movement of the higher priced chemicals was more marked than that for lower priced commodities and the drop in value was much higher than that represented by tonnage. For instance the fertilizer and oil refining industries took on relatively large amounts of sulphuric acid while there was a sharp drop in consumption of dyes which, according to the latest census data, carry an average value in excess of \$1,000 a ton.

Reports regarding activities in April indicated no change in some lines and moderate improvement in others. Improvement, however, was not extensive enough to arouse much optimism and with the peak of seasonal influences already reached, opinion has generally settled on the view that a return to active trading can not be expected until after the hot weather period.

Possibly because prices for most chemicals were relatively low and production costs higher than a year, there has been a stability to values which is noteworthy considering the drawn out period of sub-normal buying. This does not mean that full quotations have been maintained in all cases for instances of competitive selling which has taken on the form of price cutting, have been heard. In a few cases imported

material has been a factor in disturbing domestic markets. In general, however, prices have held up well. Prices for vegetable oils were unusually steady for the last month but advances are held in check by the position of consumers in world markets.

Manufacturers' sales during March declined 23 per cent from those for March 1937, according to reports from manufacturers cooperating in the monthly joint study of the National Association of Credit Men and the Bureau of Foreign and Domestic Commerce. This decrease was about the same as the 22 per cent drop recorded in February from last year. Total net sales of manufacturers during March increased 16 per cent from February 1938 without adjustment for seasonal variation. This compares with an increase of 19 per cent from February to March in 1937.

Every major industry group for which sales data are shown registered a decrease in sales during March 1938 from March of last year. The smallest decline was registered by the Printing, Publishing and Allied Industries Group, whose sales were down 2 per cent on this comparison. Other decreases ranged down to the drop of 52 per cent recorded by the Iron and Steel Products Group.

For chemicals and allied products, sales in March were reported at an advance of 22.5 per cent over those for the preceding month but at 16.7 per cent below those for March 1937.

The National Fertilizer Association reports that superphosphate production in March was slightly higher than in February, in contrast to a usual seasonal decline at this season. In every year from 1931 through 1936 March production was below February. Output was 30 per cent less than in March of last year, however, with a particularly sharp drop occurring in the Southern Area. Total production in the first nine months of the current fiscal year, from July through March was only one per cent above the preceding year. Production in the first quarter of 1938 underran the corresponding period of 1937 by 20 per cent. It now seems likely that production in the present fiscal year as well as in the calendar year 1938 will be somewhat smaller than last year.

An improved single trip container for alcohol and other solvents will go into use July 1 under authority of the Interstate Commerce Commission. While the new container, which is nine and one-

half pounds lighter than the container now being used, may be used only once for the transportation of liquids rated as dangerous, it is expected that it will be found valuable thereafter for shipments of oils and other liquids. The new drum is built according to specifications recommended by the Steel Barrels and Drums Committee of the Manufacturing Chemists' Association. It will cost twenty or twenty-five cents less to produce than the present drum. Since 8,000,000 of these drums are produced each year the saving is substantial.

Under the leadership of a steadily advancing market for borax, the output of natural sodium compounds was on a rising scale last year. Sales of borax were approximately 14 per cent ahead of the 1936 total. Shipments of natural carbonate of soda increased 2 per cent and natural sulphates showed a 55 per cent gain with production reported at the record figure of 80,053 tons.

The director of the Census, announces that factory production of fats and oils (exclusive of refined oils and derivatives) during the three month period ending March 31, 1938, was as follows: Vegetable oils, 962,736,893 lb.; fish oils, 39,446,777 lb.; animal fats, 454,765,615 lb.; and greases 80,484,263 lb.—a total of 1,537,433,548 lb. Of the several kinds of fats and oils covered by this inquiry, the largest production, 595,684,051 lb., appears for cottonseed oil. Next in order is lard with 299,874,140 lb.; tallow with 153,801,736 lb.; linseed oil with 125,587,390 lb.; soybean oil with 81,570,327 lb.; coconut oil with 74,655,516 lb.; corn oil with 31,972,613 lb.; peanut oil with 22,187,962 lb.; castor oil with 14,045,302 lb.; and babassu oil with 11,965,280 lb.

Production of refined oils during the period was as follows: Cottonseed, 579,612,544 lb.; coconut, 70,287,534 lb.; peanut, 14,782,890 lb.; corn, 36,859,616 lb.; soybean, 51,864,348 lb.; palm-kernel, 3,929,005 lb.; palm, 28,196,457 lb.; and babassu, 7,366,291 lb. The quantity of crude oil used in the production of each of these refined oils is included in the figures of crude consumed.

## CHEM. & MET. Weighted Index of CHEMICAL PRICES

Base=100 for 1935

This month	100.32
Last month	100.30
May, 1937	101.76
May, 1936	98.64

Price changes were of minor importance with practically all heavy chemicals quoted at unchanged levels. Cyanides offered an exception and were lowered in price and a few of the smaller tonnage chemicals were under selling pressure.

## CHEM. & MET. Weighted Index of Prices for OILS AND FATS

Base=100 for 1935

This month	80.25
Last month	80.66
May, 1937	113.76
May, 1936	89.35

Although there was a slight drop in the index number, values for oils and fats seemed to resist further declines and prices are in a position to respond to any buying influence.